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ANALYSIS OF FIDELITY REQUIREMENTS FOR ELECTRONIC EQUIPMENT MAINTENANCE

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The purpose of this study was to determine the transfer of training to actual equipment derived from training on modified printed circuit boards with varying numbers of simulated test points represented photographically and in three dimensions. The problem addressed was how much fidelity is required to achieve desired training effects.

Subjects in the experimental phase were 99 Navy recruits in Electronic Technician Splice Modules 30 - 34 of the Basic Electricity and Electronics

20. Abstract (cont'd)

school at Orlando Naval Training Center. Students were classified as high, medium or low proficiency based on completion time of the previous self-paced course modules.

A three-way analysis of variance design was used for the main independent variables of fidelity (three-dimensional vs two-dimensional boards), three levels of test point availability (100%, 67%, 33%), and three trainee proficiency levels. Three different circuit boards were utilized in the study; an FM Radio First IF Amplifier board, FM Radio Second IF Amplifier board and a Power Supply board. Each had three fault group types.

The dependent variables were number of test points probed, time to probe, and number of trips to the learning supervisor before fault localization.

The results indicated no significant differences when comparing the experimental treatments to the control group. The control group trained on unmodified boards tended to have an equal or higher number of probes, and equal or more probe time during testing than the students trained on lower fidelity boards. The control group trained on unmodified boards did not have a significantly higher troubleshooting success rate than students trained on modified boards.

EXECUTIVE SUMMARY

The general assumption in the training industry is that actual equipment is more costly and effective in training for troubleshooting to the component level, while trainers are less expensive and less effective due to the limited number of test points and reduced visual fidelity. The questions addressed in this report are whether actual equipment is more effective and whether the assumption is true that more test points are better. The purpose of this study was to determine the transfer of training to actual equipment derived from training on modified printed circuit boards with varying numbers of simulated test points represented photographically and in three dimensions. The problem addressed was how much fidelity is required to acnieve desired training effects.

Subjects in the experimental phase were 99 Navy recruits in Electronic Technician Splice Modules 30 - 34 of the Basic Electricity and Electronics school at Orlando Naval Training Center. Students were classified as high, medium or low proficiency based on completion time of the previous self paced course modules.

Subjects in the experimental study were tested using modified actual equipment in order to eliminate the expense of creating a software package to control specialized hardware. Printed circuit boards normally used in the trainer were modified to control access to test points. This modification was based on test points probed by students during the initial data acquisition. Boards were modified to give access to points probed by 100%, 67%, and 33% of the students.

Potential test points were created by soldering a short copper wire to the test point. Then the boards were sprayed with clear varnish to place an insulating coat over the entire board. Test points were made accessible by cutting away the coating on the end of the wire. By cutting away the varnish on different numbers of potential test points, experimental groups of test subjects were trained with varying numbers of accessible test points for hands-on practice. This approach simulates the effect of varying numbers of accessible test points on a high fidelity, three-dimensional simulation of a printed circuit board. Two-dimensional fidelity was simulated by mounting a photograph above the board and projecting a wire from each actual test point through the photograph of the point.

A three-way analysis of variance design was used for the main independent variables of fidelity (three dimensional boards vs two-dimensional boards), three levels of test point availability (100%, 67%, 33%), and three trainee proficiency levels. Three different circuit boards were utilized in the study; an FM Radio First IF Amplifier board, FM Radio Second IF Amplifier board and a Power Supply board. Each had three fault group types. Order effects were counterbalanced through a modified Greco Latin Square design. Trainees were processed through the experimental station as part of their course work.

The dependent variables were number of test points probed, time to probe, and number of trips to the learning supervisor before fault localization.

When the subject trainees were ready for a practice session on one of the boards used in the study, they were assigned to the research station. The experimenter gave the trainee a prefaulted board modified to one of the seven treatment conditions. Subjects proceeded to troubleshoot the board and take their exercise sheets to the school's learning supervisor for grading. This step was repeated with an identical board and treatment condition, but a different fault. When the learning supervisor determined the subject had mastered the board, the trainee was given an unmodified board to troubleshoot. This test was the criterion performance to measure transfer of training to actual equipment after practice on modified boards.

The research compared treatment conditions and a control in a strict experimental environment. The results indicated no significant differences when comparing the experimental treatments to the control group. The control group trained on unmodified boards tended to have an equal or higher number of probes, and equal or more probe time during testing than the students trained on lower fidelity boards. The control group trained on unmodified boards did not have a significantly higher troubleshooting success rate than students trained on modified boards. On several boards, the proportion of success to failure tended to be better after training on modified 2D boards. Overall, the significant and non-significant data indicate that actual equipment is not superior to modified equipment for electronic training in this environment.

Student proficiency level within this school strongly affects the student's troubleshooting results. Low proficiency students, as expected, took a longer time to localize faults and probed more points than medium or high proficiency students. These expected results and their consistency supports proficiency level, as detailed for this analysis, as a valid performance predictor.

For this type of hands-on electronics maintenance training, the research has shown that low fidelity simulation can be as effective as high fidelity trainers or actual equipment. Performance indicates that lower fidelity training with reduced test point accessibility can decrease fault localization time and number of probes during testing. Transfer-of-training to actual equipment appears to be enhanced by selective test point reduction, not one-to-one fidelity with the actual equipment.

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SECTION I

INTRODUCTION

Over the last few years, computer simulated maintenance trainers (trainers) have made significant inroads against actual equipment trainers (AETs) in hands-on electronic maintenance training. Orlansky & String (1981) reviewed 13 evaluations of the relative effectiveness of maintenance trainers and AETs. In 12 of these evaluations, students trained on maintenance trainers had equal or superior end-of-course scores when compared to students trained on actual equipment. In addition, training time was cut 22 to 50 percent.

Cicchinelli, et al. (1980) compared supervisors' ratings of on-the-job performance of technicians trained either on a three-dimensional maintenance trainer or AET. Their ratings showed no noticeable difference between the performance of technicians trained with the trainer or AET.

Trainers have proven the capability to provide equal or superior training at a lower life-cycle-cost when teaching troubleshooting based on front panel indications, failure symptoms and some in-drawer visual indicators. However, in the area of hands-on troubleshooting to the component level, the relative cost-effectiveness of AETs versus trainers is not clearly understood. Actual equipment trainers are a higher fidelity simulation of the field equipment and theoretically should provide better transfer of training. However, high AET purchase costs, lower reliability and low student/instructor ratios lead to high life-cycle-costs. Trainers generally have a lower life-cycle-cost, but these savings are accompanied by a reduced fidelity, especially a reduced number of accessible test points. Simulation engineers indicate that if all test points on a circuit board (50-100 points) are simulated, the complexity of modeling the correct test equipment readings for each failure at every point becomes prohibitive.

Another difference between AETs and trainers is that trainers may utilize a photograph of a circuit board with simulated test points available in appropriate locations. The training effects of this reduced fidelity of simulation have not yet been determined.

The general assumption is that an AET is more costly and effective in training for troubleshooting to the component level, while trainers are less expensive and less effective due to the limited number of test points and reduced visual fidelity. The questions are whether AETs are more effective and whether the assumption is true that more test points are better. Engineers can estimate the cost of a trainer for various numbers of simulated test points and varying visual representation based on previous experience. The question remains as to the relative effectiveness of a trainer depending on the fidelity of simulation and number of test points simulated. The purpose of this study was to determine the transfer of training to actual equipment derived from training on modified printed circuit boards with varying numbers of simulated test points represented photographically and in 3 dimensions.

The hypotheses to be tested were:

1. Training on a two-dimensional circuit board is as effective as training on a three-dimensional circuit board.
2. Training with a reduced number of test points available is as effective as training with all test points available.
3. High proficiency students will perform as well after training on two-dimensional boards with reduced test points available, and low proficiency students will perform better after training on actual printed circuit boards than after training on reduced accessibility and fidelity boards.

SECTION II

METHOD

The primary objective of the research program was to evaluate the transfer of training to a typical electronic troubleshooting task when students were trained on electronic modules with varying numbers of potential test points and 2 levels of visual fidelity. Since the purpose of the study was to look at various levels of simulation fidelity, the most apparent approach was to build a trainer varying both the number of test points and levels of physical fidelity, and to measure transfer of training to actual equipment. Developing such a trainer would have been quite complex and expensive. But the ability to simulate various numbers of test points was not the issue under consideration. The issue to be addressed was how effective is training with varying numbers of potential test points on equipment simulated photographically and in 3 dimensions.

The least expensive approach to gathering these data was to utilize actual equipment, restrict the number of test points available for student probing, and to vary the apparent physical fidelity by overlaying actual boards with photographs so that the trainee could not see the actual components being tested.

Since the results of this study were intended for use by designers of military electronics training equipment, a decision was made to gather the data at the Basic Electricity and Electronics (BE&E) School at the Naval Training Center in Orlando, Florida. Subjects were students in the Electronic Technician (ET) Splice Course of the BE&E School.

Since complexity of the troubleshooting task was certain to affect student troubleshooting behavior, 3 different printed circuit boards were utilized in the study: a simple Second IF Amplifier (Second IF), a medium complexity First IF Amplifier (First IF) and a highly complex Power Supply (Power Supply) board with feedback loops. These boards were contained in a NIDA Model 205 Transceiver Trainer and a NIDA Model 201 Power Supply Trainer utilized as a normal part of the curriculum in the ET Splice Course.

Each of the 3 boards was prefaulted by the manufacturer. Nine different faults were prepared for each board to prevent student word of mouth from eliminating the need to troubleshoot. The faults in each board were grouped into 3 fault groups. The 3 faults in each group were selected such that the required minimum number of probes to locate the faults would overlap 90%.

MODIFICATION OF ACTUAL EQUIPMENT

Figures 1 and 2 indicate the approach for modifying actual equipment to control the number of test points accessible to the student. Potential test points were created by soldering a short copper wire to the test point. Then the boards were sprayed with a clear conformal coating a sufficient number of times to place an insulating coat over each point. Test points were made accessible by cutting away the

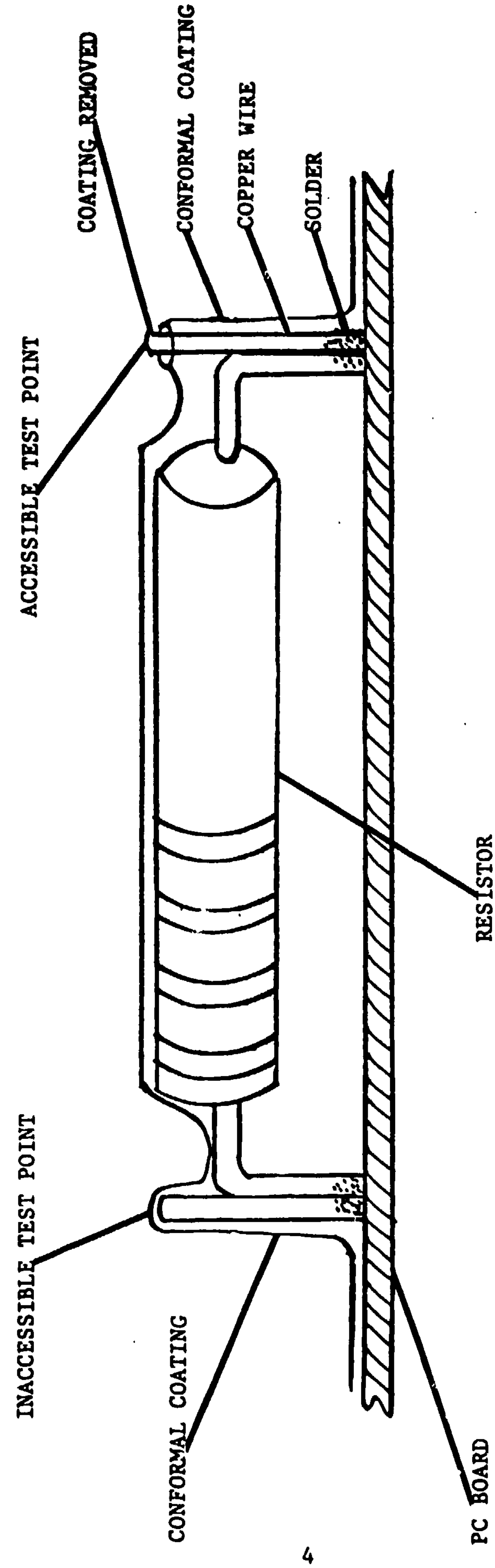

Figure 1. Modification of actual equipment to control accessibility to test points.

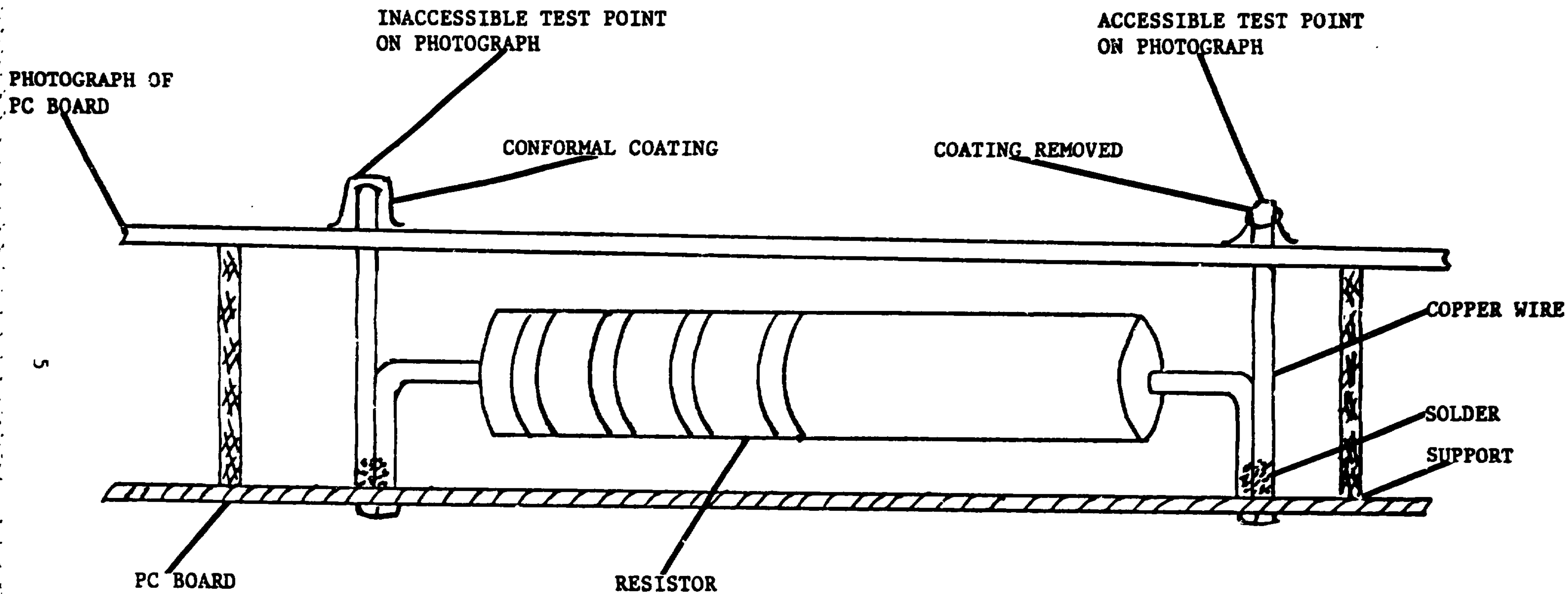

Figure 2. Modification of actual equipment to control accessibility of test points on photograph.

coating on the end of the wire. By cutting away the coating on potential test points, a progressively higher number of accessible test points could be made available for probing on different prefaulted boards. Figure 3 illustrates an actual printed circuit (PC) board modified to control student access to test points. The approach in Figure 3 simulates the effect of varying numbers of accessible test points on a high fidelity, three-dimensional (3D) simulation of a PC board.

The approach in Figure 4 simulates the effect of varying numbers of test points on a photographic two-dimensional (2D) simulation of a PC board. A photograph of a PC board was mounted above the actual board. Test points were created by placing a hole in the photograph, projecting the copper wire through, and insulating it with conformal coating. Test points were then made accessible by cutting away the coating in the same manner as above.

TEST POINT SELECTION

Once the procedure for creating test points had been developed, the question arose as to which test points were to be made accessible. One alternative was to select points that matched the failure symptoms being demonstrated on the electronic module. However, trainees are not always that rational in their probing of test points. By simulating only the logical test points based on the symptoms, the trainee would be unnecessarily channeled toward the correct response, leaving little opportunity to demonstrate whether the correct troubleshooting procedure had or had not been learned. The most effective way to select test points was to observe trainees during hands-on practice on actual equipment and record which test points they probed for each fault with all test points active.

INITIAL DATA ACQUISITION

Initial data were collected to determine the points most frequently probed by ET Splice students. These initial data were required in order to select the points to be exposed during the experimental phase. This initial phase also provided data for the definition of student proficiency levels.

STUDENT PROFICIENCY LEVELS. It was hypothesized that student proficiency would significantly affect student troubleshooting behavior. Since the BE&E course is self-paced, it was assumed that higher proficiency students would complete the course in less time than lower proficiency students.

The initial student proficiency categories were determined by taking a random sample of 114 BE&E Splice completion times from the BE&E school computer managed instruction (CMI) printouts, and dividing the range of times into 3 equal groups. This resulted in a high proficiency range of 145 - 207.99 hours to complete BE&E modules 1 through 29, a medium proficiency of 208 - 257.99 hours, and a low proficiency of 258 - 334.99 hours. During the initial data collection period, student completion times for the BE&E course increased above

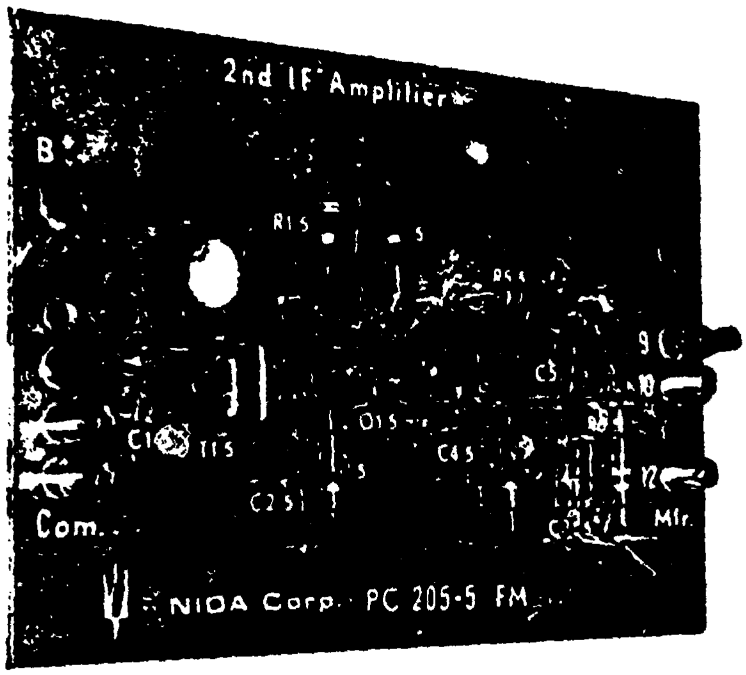

Figure 3. Three-dimensional simulation.

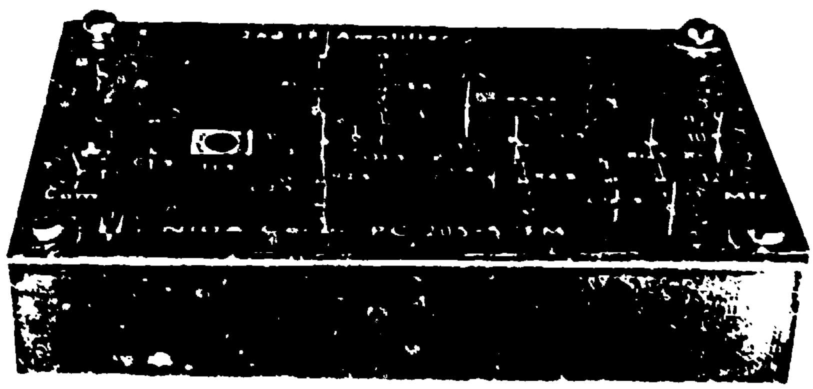

Figure 4. Two-dimensional simulation.

that of the initial sample. The initial BE&E Splice proficiency levels were revised to reflect an additional 111 students monitored through the initial data gathering period. The resulting final proficiency levels were: high 0 - 224.99 hours, medium 225 - 289.99 hours, and low 290 - 365.99 hours.

OBSERVATIONS OF STUDENT TROUBLESHOOTING. Students were observed during regularly scheduled course modules. Troubleshooting performance tests were observed for the Module 30-2 Power Supply and the Module 31-3 Transceiver First and Second IF Amplifiers. Forty-five students (fifteen in each proficiency level) were observed taking a total of 130 performance tests. No changes were made in the existing curriculum except for 2 additional troubleshooting performance tests at the researcher's table. The research trainers were identical to the Transceiver and Power Supply trainers used by the school and were manned by 1 on-site researcher. The printed circuit boards utilized during this phase were unmodified boards normally used at the school.

Observation of student troubleshooting resulted in obtaining the following data:

1. Number of students probing each test point.
2. Sequential order of probes.

TEST POINT SELECTION. The number of students probing each test point provided the data to be used in modifying the 2D and 3D component boards used in the experimental phase of the study. Points were ranked from highest to lowest based on the percentage of students probing each one (i.e. ranked from points probed by all students to those not probed). Those points not probed by any students were eliminated. The number of points eliminated ranged from 0 - 4 on all boards except one which had 11 unprobed points. The remaining points were divided into 3 groups. The test points exposed in the experimental phase represented 100%, 67%, and 33% of the points probed by students in the initial phase. The 100% category had the highest number of points accessible and represented all points probed by one or more students in the initial phase. Test points not probed by any student during initial data acquisition were not included. The 67% category had two-thirds of the points accessible, eliminating those probed by only a few students. Test points not probed by any student and the lowest third of the frequency distribution were not included. The 33% category contained one-third of the total original number of points, representing only those probed by the majority of students. This category contained only points ranked in the top third of the frequency distribution.

Once the data were gathered on student probing of test points, the boards were modified to restrict access to test points, as indicated in Table 1. Then 2D and 3D boards were created for each of the 9 faults in each of the 3 boards for a total of 54 modified boards.

TABLE 1. TEST POINT ACCESSIBILITY

BOARD	FAULT GROUP	FAULT	MINIMUM TESTS REQUIRED	TOTAL TEST POINTS	TEST POINTS ACCESSIBLE 100%	67%	33%
SECOND IF							
	1	CR1 Open	7	42	42	22	12
		R6 Open	7		42	22	12
	2	R2 Open	11		42	28	17
		Open VCC Run	10		42	28	17
	3	Q1 Short B-C	11		41*	28	17
		Open Run R5/Ca5 Junction to Pin 10	10		41	28	17
FIRST IF							
	1	Q2 Short C-E	9	74	71*	64	27
		Q2 Short B-C	9		71	64	27
	2	R8 Open	9		69	41	25
		T1 Secondary Open	9		69	41	25
	3	R3 Open	9		64	41	21
		Q1 Open B-E	9		64	41	21

TABLE 1. TEST POINT ACCESSIBILITY (CONT'D)

BOARD	FAULT GROUP	FAULT	MINIMUM TESTS REQUIRED	TOTAL TEST POINTS	TEST POINTS ACCESSIBLE 100%	67%	33%
POWER SUPPLY							
	1	CR3 Short	9	83	79*	57	29
		R9 Open	9		79	57	29
	2	CR4 Short	9		79	56	28
		Q6 Open B-E	9		79	56	28
	3	Q8 Open B-E	10		78	61	32
		R15 Open	10		78	61	32

Note: *Points in the 100% accessibility group may be less than the total test points, because poi[illegible] not probed by any students were eliminated.

EXPERIMENTAL PHASE

During the experimental phase of the study, students practiced on modified boards with varying levels of visual fidelity and test point accessibility. They were then tested on unmodified boards to test the transfer of training to actual equipment for each experimental treatment.

SUBJECTS. Research subjects in the experimental phase were male and female Navy recruits, with the rank of E3 Seaman. Students' ages ranged from 17 to 35 years with a mean of 19 years. Most students' education levels ranged from a high school diploma to 1 year of college. These subjects were students in the ET Splice modules 30-34 of BE&E training.

Students were selected at random from Computer Managed Instruction printouts such that an equal number of students were from high, medium and low proficiency groups. Initially, the study had planned to test 62 repeated subjects on all 3 types of boards (Power Supply, First IF Amplifier, and Second IF Amplifier) used in the experimental phase. A number of performance tests (46) had to be voided due to a large number of BE&E unmodified prefaulted component boards with more than 1 fault, student attrition, and faulty training equipment. This, along with time constraints, led to a partial repeated measures using additional subjects to fill in boards. This resulted in a total of 186 performance tests (including 27 control performance tests) from a total of 99 students.

Of the 99 students tested, 29 were tested on all 3 boards used in the experimental phase. This accounts for 87 of the performance tests as total repeated measures. Out of these 29 students, 2 were randomly assigned as controls on 2 of the 3 possible board types, and 8 were used as controls on 1 out of 3 possible board types.

Of the total 99 students, 29 were tested on 2 out of the 3 possible types of boards, accounting for an additional 58 performance tests. Of these 29, 8 students were randomly chosen as controls. A total of 58 students saw 2 or more board types.

The remaining 41 students were tested on 1 of the 3 possible board types. This accounts for an additional 41 performance tests. Of these 41 students, 7 were randomly chosen to be controls. Student assignment to board type and treatment was carefully controlled by the experimental matrix. Equipment malfunction and student attrition only affected the completion of the total repeated measures. The experimental matrix completely randomized and balanced all treatment and control factors.

The BE&E course is a preparatory course for the Electronic Technician rating. The course is self-paced, and students proceeded through the research station as part of their regular course work. Student performance on the experimental circuit boards did not affect their class status. Average course completion time is 65 classroom hours. The standard curriculum includes 7 training exercises and 7 performance tests on 7 circuit boards in 3 trainers. The data gathered in this study encompassed 3 of the training exercises and 3 of the performance tests on 2 of the trainers.

PROCEDURES. BE&E Splice completion times, obtained from the CMI, were used to assign each student to a proficiency level of high, medium, or low developed during the initial data acquisition. Sixty-two performance tests were observed on each of the 3 boards used in the Power Supply and Transceiver trainers. A total of 9 control performance tests were administered on each of the 3 boards, consisting of 1 training exercise on an unmodified printed circuit board followed by 1 graded criterion performance test on an additional unmodified board. The remaining 53 performance tests for each board were comprised of 1 training exercise on a printed circuit board, modified by treatment condition, followed by a criterion performance test on an unmodified board. A total of 159 performance tests were from students trained on modified boards (experimental group), and 27 were from students trained on unmodified boards (control group).

Initially, the unmodified prefaulted component boards for the control group and the criterion tests were supplied by the training school, but due to logistic considerations, it was decided that we should provide our own. Due to a limited supply of unmodified boards and the time factor involved in ordering additional boards, it was decided to use 2 out of 3 faults in each of the designated fault groups for the unmodified boards. A complete set of 9 prefaulted, 2D and 3D modified boards were used for each of the Power Supply and First IF and Second IF Amplifier boards.

When students progressed to a point in the curriculum where they were ready to take their performance tests on the Power Supply board, the First IF board, or the Second IF board, they were referred to the researcher's testing area by their Learning Supervisor (LS). The researcher then consulted the CMI information gathered previously to determine the student's assigned proficiency level, and the student would be given a prefaulted printed circuit board in 1 of the 7 possible treatment conditions. If the equipment was full, or the student's proficiency level was not needed to finish the experimental phase, the student would be referred back to the LS and not used in the study.

Students assigned 1 of the 7 possible treatment conditions in the researcher's testing area proceeded to troubleshoot the faulty board and fill in the required information on the Troubleshooting Performance Response Sheets provided by the school for performance tests. The response sheets were then taken to the student's LS for grading. After receiving feedback from the LS on their performance, students would return and, if necessary, troubleshoot the same board further until they found the fault. Once the fault was correctly localized, response sheets were given to the researcher, and students were issued a second, unmodified prefaulted component board to troubleshoot. The student again filled out a response sheet and went to an LS for feedback. Upon finding the fault, the student returned the response sheet to the researcher. The second, unmodified performance test was the criterion measure to determine transfer of training to actual equipment after a training exercise on a modified board.

Specific points probed, total number of probes, probing time, student comments, and other pertinent data were recorded by the researcher during both the modified and unmodified troubleshooting sessions. These data led to analysis of the effects of simulation fidelity and test point accessibility during training on trouble-shooting behavior during testing on actual equipment. These data are discussed in the Results section of this paper.

EXPERIMENTAL DESIGN

The three-dimensional design matrix was a 2 (Physical Fidelity) by 3 (Test Point Accessibility) by 3 (Proficiency Level) design with an external control and had 3 replications across Circuit Boards. Fault groups were used as a control factor within each cell. This matrix is represented in 3 dimensions in Figure 5. The main independent variables were training fidelity (3D boards vs photographic 2D boards) and training test point accessibility (100% vs 67% vs 33%) with a control group (unmodified boards). The effects of fault group and proficiency level were controlled by matching them in each cell to reduce extraneous variance. The dependent variables under study were number of test points probed, probing time, and number of trips to the Learning Supervisor before fault localization. These data were gathered on modified boards during training and on criterion performance tests after training.

The main effects of the matrix were analyzed using a three-way Analysis of Variance (ANOVA) (Ferguson, 1976) design replicated across 3 PC boards. This analysis allowed the simultaneous investigation of the independent and combined effects of test point accessibility, physical fidelity, and student proficiency level. Each student was classified in 1 proficiency level and exposed to 1 set of experimental conditions within each board. The design was not a repeated measures when the 3 boards were analyzed separately. Therefore, the within cells sum of squares was used as the ANOVA error term.

The external control group was analyzed against all experimental groups in independent analyses. These ANOVAs examined any performance differences between the experimental groups and the control group. The external control group was not exposed to test point accessibility or fidelity, but did receive a proficiency classification and the fault group control factors.

The dependent variables examined by the ANOVAs were the number of probes and time to locate the fault on criterion (unmodified) boards after training in 1 of the treatment configurations. This analysis of criterion performance indicated the degree of transfer of training from the treatment conditions.

In addition to analysis of the criterion performance, actual training performance on modified boards was examined. These data indicated any performance differences during training on modified or

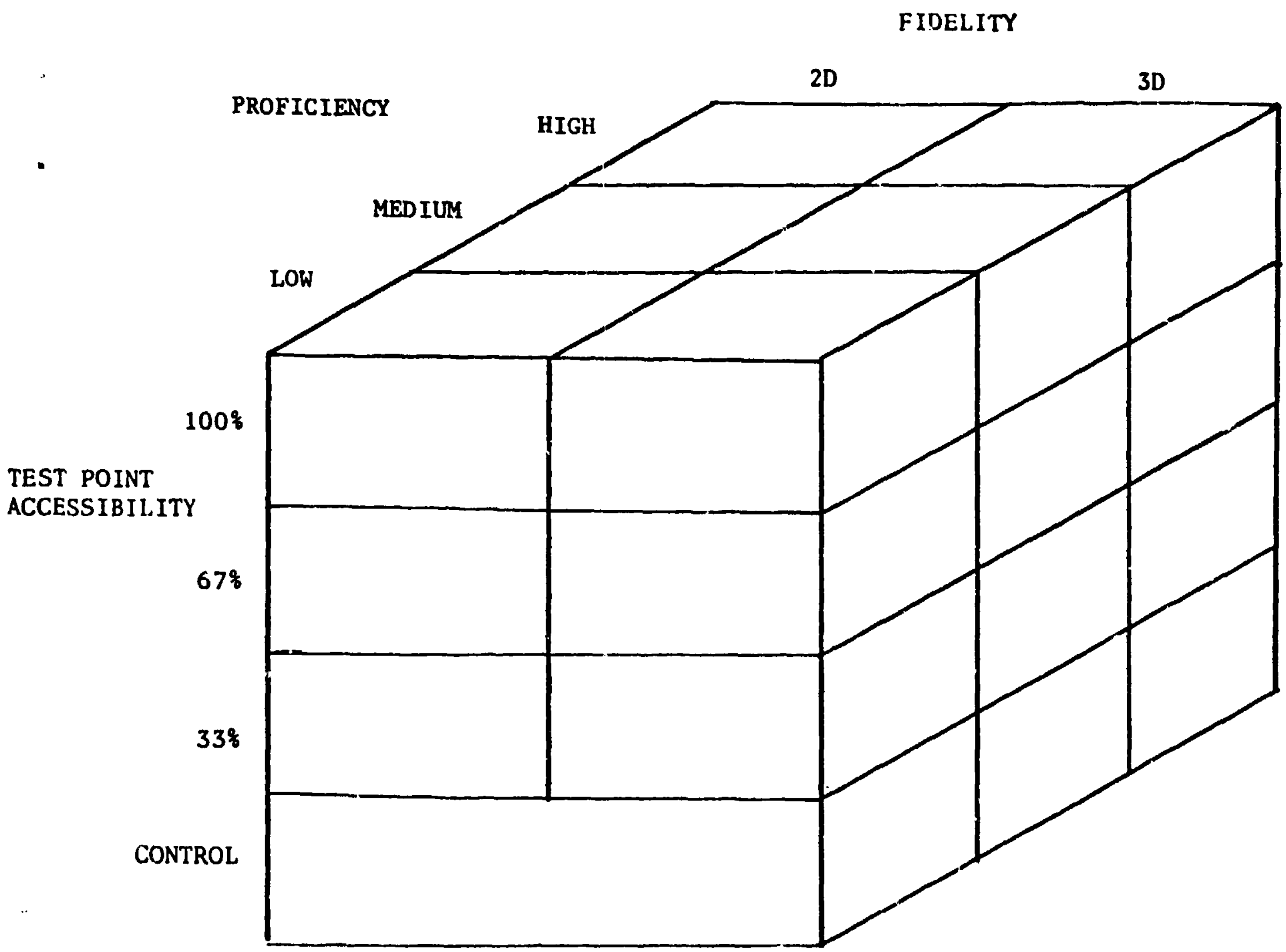

Figure 5. Experimental design matrix.

unmodified boards. The dependent variables were number of probes and time to locate the fault.

The number of student trips to the Learning Supervisor (LS) was dichotomized into whether or not the student was correct the first time. These data were analyzed by Chi Square analysis (Siegel, 1956) on the criterion performance. This analysis allowed examination of the frequency differences in trips to the LS, between the treatment conditions.

The experimental design and data analysis was an effort to prove the null hypothesis, i.e. that there is no difference between the control group and the experimental group. The analysis also examined effects between treatments. The level for significant difference was .05, i.e. there must be a 95% probability that the difference is not due to chance. The three-way ANOVAs were used to discover any significant difference between the treatment conditions. Again, the probability level for significance was set at .05.

Analysis of Variance procedures only indicated that there were significant differences between treatment conditions. In order to ascertain where the significant differences were occurring, a Fisher Least Significant Difference (LSD) post hoc procedure (Wilkowitz, et al., 1976) was performed on all significant ANOVA F tests, using a probability level for significance of .05. This allowed a comparison of all possible paired means using a more stable estimate of the population variance, Mean Square Within, which pools all the sample variances.

SECTION III

RESULTS

ANALYSIS OF VARIANCE - MAIN EFFECTS - CRITERION PERFORMANCE

The results discussed in this section examine differences in testing (criterion) performance after training on modified boards. The main effects of test point accessibility, fidelity, and proficiency were examined within the 3 board types. The primary measures of effectiveness were number of probes and time to locate the fault during fault isolation on criterion (unmodified) boards. The 3 boards were analyzed in this section as separate ANOVA designs.

POWER SUPPLY BOARD - TREATMENT MAIN EFFECTS. The ANOVA source and summary, Tables 2 - 5, for the Power Supply board, indicate no significant ($p<.05$) performance effects due to the treatment conditions for probe time or points probed during testing. These tables indicate no performance differences among treatments or between them on the dependent variables.

POWER SUPPLY BOARD - TREATMENTS VERSUS CONTROL GROUP. A series of two-way ANOVAs were used to examine any criterion performance differences between the treatment conditions and the control group. The control group data are contained in Table 6. ANOVA results indicated that there were no significant performance differences between treatments and control on probe time or number of points probed.

SECOND IF - TREATMENT MAIN EFFECTS. The ANOVA totals and summary data for points probed are shown in Tables 7 and 8. These data indicate a significant ($p<.05$) effect due to test point accessibility and an interaction effect between accessibility and fidelity and between fidelity and proficiency. A significant interaction indicates an inconsistent effect of a variable across the remaining variables.

The least significant difference (LSD) post hoc technique was applied to determine exactly which variable differences were significant. The LSD uses the smallest value which can be considered significant. This technique examines all the pair-wise mean differences within a variable (e.g. accessibility) to determine which difference is the source of significance. Table 9 contains the accessibility mean data. The LSD indicated a significant ($p<.05$) difference in points probed between 100% and 67% accessibility.

Table 10 contains the mean points probed for the accessibility/fidelity interaction. The analysis indicated that students trained with the 3D/100% treatment probed significantly ($p<.05$) more points than the students trained with the 3D/33% treatment.

Table 11 contains the mean data for the fidelity/proficiency interaction. The LSD analysis indicated that after 2D training, the medium proficiency group probed significantly ($p<.05$) fewer points than the low proficiency group, during testing.

TABLE 2. POWER SUPPLY - CRITERION PERFORMANCE - PROBE TIME (MINUTES)

ANOVA DATA TOTALS

	THREE-DIMENSIONAL			TWO-DIMENSIONAL		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
100%	252	213	259	182	178	126
67%	243	243	216	171	197	233
33%	163	137	222	291	191	202

TABLE 3. POWER SUPPLY ANOVA - CRITERION PERFORMANCE - PROBE TIME (MINUTES)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility (A)	334.7	2	167.35	.14
Fidelity (F)	580.16	1	580.16	.47
Proficiency (P)	596.03	2	298.01	.24
A x F Interaction	4591.45	2	2295.73	1.86
A x P Interaction	1196.19	4	299.04	.24
F x P Interaction	498.79	2	249.40	.20
A x F x P	2846.77	4	711.69	.58
Within Cells	44432.00	36	1234.22	
Total	55076.09	53		

Note: No Significant Effects

TABLE 4. POWER SUPPLY - CRITERION PERFORMANCE - POINTS PROBED

ANOVA DATA TOTALS

	THREE-DIMENSIONAL			TWO-DIMENSIONAL		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
100%	213	201	337	265	159	114
67%	413	153	293	208	275	250
33%	196	201	162	252	275	198

TABLE 5. POWER SUPPLY ANOVA - CRITERION PERFORMANCE - POINTS PROBED

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility (A)	3457.37	2	1728.68	.81
Fidelity (F)	554.21	1	554.21	.26
Proficiency (P)	2322.92	2	1161.46	.54
A x F Interaction	4379.15	2	2189.57	1.00
A x P Interaction	3314.63	4	828.65	.39
F x P Interaction	4224.93	2	2112.47	.98
A x F x P	11318.85	4	2829.71	i.32
Within Cells	77252.00	36	2145.89	
Total	106824.06	53		

Note: No Significant Effects

TABLE 6. POWER SUPPLY BOARD - CONTROL GROUP-
CRITERION PERFORMANCE

	MEAN	VARIANCE
Points Probed	64.67	2678.06
Probe Time	63.00	1209.64

TABLE 7. SECOND IF - CRITERION PERFORMANCE - POINTS PROBED

ANOVA DATA TOTALS

	THREE-DIMENSIONAL			TWO-DIMENSIONAL		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
100%	245	230	207	186	87	122
67%	217	88	88	63	109	126
33%	112	116	67	68	100	362

TABLE 8. SECOND IF ANOVA - CRITERION PERFORMANCE - POINTS PROBED

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility (A)	4267.70	2	2133.85	2.35*
Fidelity (F)	400.17	1	400.17	.44
Proficiency (P)	1686.07	2	843.04	.93
A x F Interaction	7745.33	2	3872.67	4.27*
A x P Interaction	6299.71	4	1574.93	1.73
F x P Interaction	7744.07	2	3872.04	4.27*
A x F x P	8439.26	4	2109.82	2.32
Within Cells	32634.67	36	906.52	
Total	69216.98	53		

Note: * $p<.05$

TABLE 9. SECOND IF - CRITERION PERFORMANCE - ACCESSIBILITY MEAN PROBE DATA

ACCESSIBILITY	MEAN POINTS PROBED
100%	59.83
67%	38.39
33%	45.83

TABLE 10. SECOND IF - CRITERION PERFORMANCE - ACCESSIBILITY/FIDELITY INTERACTION - MEAN POINTS PROBED

	FIDELITY	
ACCESSIBILITY	TWO-DIMENSIONAL	THREE-DIMENSIONAL
100%	43.89	75.78
67%	33.11	43.66
33%	58.89	32.78

TABLE 11. SECOND IF - CRITERION PERFORMANCE - FIDELITY/PROFICIENCY INTERACTION - MEAN POINTS PROBED

	FIDELITY	
PROFICIENCY	TWO-DIMENSIONAL	THREE-DIMENSIONAL
High	35.22	63.78
Medium	32.89	48.22
Low	67.78	40.22

The ANOVA data and summary for probe time are shown in Tables 12 and 13. The only significant effect was in the variable of proficiency ($p<.05$). The post hoc LSD indicated the high proficiency students had less ($p<.05$) probe time than the low group (Table 14).

SECOND IF - TREATMENTS VERSUS CONTROL GROUP. The control data are shown in Table 15. The ANOVA tests between treatment conditions including control, on points probed, indicated a significant ($p<.05$) interaction between proficiency and fidelity with the control group as a level of fidelity (Table 16). However, a simple pair-wise post hoc failed to find significance, indicating a combined higher order interaction. The value of analyzing a complex pair-wise combination is negligible. The ANOVAs using the control group on time to probe failed to indicate any significant differences.

FIRST IF - TREATMENT MAIN EFFECTS. The ANOVA data and summary for number of points probed and probe time are shown in Tables 17 - 20. The analysis indicated that there were no significant ($p<.05$) differences in testing performance after training on modified boards.

FIRST IF - TREATMENTS VERSUS CONTROL GROUP. The control group data are contained in Table 21. The ANOVAs failed to indicate any performance differences between treatment conditions and the control group on criterion performance.

ANALYSIS OF VARIANCE - BOARD EFFECTS - CRITERION PERFORMANCE

The data gathered did not meet the assumptions necessary to conduct an independent or repeated measures factorial analysis or a randomized block design between board types. Of the 99 subjects participating, 29 were exposed to all 3 board types, 29 saw 2 types, and 41 were exposed to only 1 board (see Section II for details). To obtain an indication of performance differences between the 3 boards, an ANOVA for independent measures was performed since the data most closely matched independence. Student assignment to treatment conditions was strictly controlled and documented. However, student population flow and our extended matrix design were not conducive to a classical repeated measures. Although 29 subjects may have performance data on all 3 boards, the treatment conditions were not necessarily repeated. For example, a subject may have been exposed to the Power Supply board configured to 2D/100%, the First IF configured to 2D/33%, and the Second IF configured to 3D/67%. Thus, the data was not completely independent or repeated, and this must be considered for the results detailed in this section.

The ANOVAs for criterion performance within boards for probing time indicated only 1 main effect, i.e. proficiency. Therefore, fidelity and accessibility did not need to be separated for probe time since they are not statistically different. The control group resulted in an interaction only as a level of fidelity and was also combined with these data. A two-way ANOVA between board types and proficiency levels resulted in a significant ($p<.001$) board effect

TABLE 12. SECOND IF - CRITERION PERFORMANCE - PROBE TIME (MINUTES)

ANOVA DATA TOTALS

	THREE-DIMENSIONAL			TWO-DIMENSIONAL		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
100%	111	156	144	97	76	118
67%	109	63	79	62	129	97
33%	91	67	105	47	76	248

TABLE 13. SECOND IF ANOVA - CRITERION PERFORMANCE - PROBE TIME (MINUTES)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility (A)	744.78	2	372.39	1.19
Fidelity (F)	11.57	1	11.57	.04
Proficiency (P)	2365.78	2	1182.89	3.77*
A x F Interaction	1512.49	2	756.25	2.41
A x P Interaction	2937.79	4	734.45	2.34
F x P Interaction	1614.82	2	807.41	2.58
A x F x P	2965.63	4	741.41	2.36
Within Cells	11288.00	36	313.56	
Total	23440.86	53		

Note: * $p<.05$

TABLE 14. SECOND IF - CRITERION PERFORMANCE - PROFICIENCY MEAN PROBE TIME (MINUTES)

PROFICIENCY	MEAN TIME
High	28.72
Medium	31.50
Low	43.94

TABLE 15. SECOND IF - CONTROL GROUP - CRITERION PERFORMANCE

	MEAN	VARIANCE
Points Probed	44.78	286.29
Probe Time	33.44	328.69

TABLE 16. SECOND IF - CRITERION PERFORMANCE - FIDELITY/PROFICIENCY INTERACTION - MEAN POINTS PROBED

	FIDELITY		
PROFICIENCY	TWO-DIMENSIONAL	THREE-DIMENSIONAL	CONTROL
High	35.22	63.78	38.33
Medium	32.89	48.22	60.33
Low	67.78	40.22	35.67

TABLE 17. FIRST IF - CRITERION PERFORMANCE - PROBE TIME (MINUTES)

ANOVA DATA TOTALS

	THREE-DIMENSIONAL			TWO-DIMENSIONAL		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
100%	80	126	120	72	130	91
67%	114	100	137	72	108	78
33%	53	189	145	86	104	150

TABLE 18. FIRST IF ANOVA - CRITERION PERFORMANCE - PROBE TIME (MINUTES)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility (A)	475.70	2	237.85	.52
Fidelity (F)	554.24	1	554.24	1.21
Proficiency (P)	2578.37	2	1289.19	2.82
A x F Interaction	109.48	2	54.74	.12
A x P Interaction	1074.52	4	268.63	.58
F x P Interaction	140.54	2	70.27	.15
A x F x P	1623.85	4	405.96	.88
Within Cells	16480.00	36	457.77	
Total	23036.70	53		

Note: No Significant Effects

TABLE 19. FIRST IF - CRITERION PERFORMANCE - POINTS PROBED

ANOVA DATA TOTALS

	THREE-DIMENSIONAL			TWO-DIMENSIONAL		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
100%	124	114	200	88	285	67
67%	180	224	103	73	144	88
33%	50	202	173	101	163	163

TABLE 20. FIRST IF ANOVA - CRITERION PERFORMANCE - POINTS PROBED

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility (A)	122.81	2	61.05	.04
Fidelity (F)	726.03	1	726.03	.45
Proficiency (P)	7633.03	2	3816.52	2.38
A x F Interaction	1541.33	2	770.66	.48
A x P Interaction	2626.86	4	656.72	.41
F x P Interaction	1281.34	2	640.67	.39
A x F x P	8205.03	4	2051.26	1.28
Within Cells	57660.33	36	1601.68	
Total	79796.76	53		

Note: No Significant Effects

TABLE 21. FIRST IF - CONTROL GROUP - CRITERION PERFORMANCE

	MEAN	VARIANCE
Points Probed	36.44	852.64
Probe Time	31.78	368.83

(Tables 22 and 23). An LSD post hoc analysis indicated the Power Supply board required more probing time than the First and Second IF boards ($p<.05$).

The dependent variable of points probed could not be combined across independent variables because of significant effects found in the three-way Second IF ANOVA (Table 8). Two-way ANOVAs were used for each of the 3 independent variables to examine the effects of board type. Tables 24 through 29 show a significant ($p=.001$) effect by board type. The LSD post hoc indicated the Power Supply board required students to probe more points than the First and Second IF boards ($p<.01$). The results in Table 29 indicate a significant ($p<.05$) interaction between proficiency level and board type. The post hoc means are shown in Table 30. There was a significant ($p<.01$) difference between the Power Supply board and the First and Second IFs within the high proficiency group. In the medium proficiency group, the Power Supply board resulted in more probes than the Second IF ($p<.05$). In low proficiency, the Power Supply board resulted in more probes than the First IF ($p<.01$).

The results across board type indicated that the complex Power Supply board requires significantly ($p<.01$) more probing and troubleshooting time during fault isolation than do the lower complexity IF boards.

TREATMENT MAIN EFFECTS SUMMARY

Figures 6 and 7 show the overall performance patterns resulting from treatment and control conditions. Across the 3 boards, the Power Supply board resulted in more probing time and more points probed. The greater number of probes and probing time was expected because the Power Supply board is the most complex of the 3 boards.

Since we were attempting to prove the null hypothesis, the data trends (non-significant results) are extremely important in this research. The control group did not perform significantly better than any of the treatment conditions. Figures 6 and 7 indicate a pattern of trends (not statistically significant) in which the lower fidelity conditions resulted in performance equal to or better than the higher fidelity and unmodified control group training conditions. The significant ANOVA results support these overall trends. For example, the points probed on the Second IF after 3D/100% training were higher ($p<.05$) than after 3D/33% training.

The analysis has also indicated that the variable of student proficiency level significantly affects performance. The high proficiency students tended to require less time and points on the 2D boards, while the medium proficiency required the least time and points on the 3D boards. The hypothesized interaction between student proficiency and fidelity was confirmed on the Second IF board. High and medium proficiency students performed better after training on 2D boards, while low proficiency students performed better after training on 3D boards.

TABLE 22. BETWEEN BOARDS - PROBE TIME (MINUTES)
(INCLUDES CONTROL GROUP)

ANOVA DATA TOTALS

BOARD TYPE	PROFICIENCY HIGH	MEDIUM	LOW
Power Supply	1302	1159	1258
First IF	477	757	721
Second IF	517	567	791

TABLE 23. BETWEEN BOARDS ANOVA - PROBE TIME (MINUTES)
(INCLUDES CONTROL GROUP)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Board Type (B)	47250.60	2	23625.30	41.81**
Proficiency (P)	2696.60	2	1348.3	2.39
B x P	2482.84	4	600.71	1.10
Within	101714.04	180	565.08	
Total	154144.08	188		

NOTE: ** $p<.01$

TABLE 24. BETWEEN BOARDS - POINTS PROBED (INCLUDES CONTROL GROUP)

ANOVA DATA TOTALS

	FIDELITY	
BOARD TYPE	TWO-DIMENSIONAL	THREE-DIMENSIONAL
Power Supply	1996	2169
First IF	1172	1370
Second IF	1223	1370

TABLE 25. BETWEEN BOARDS ANOVA - POINTS PROBED (INCLUDES CONTROL GROUP)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Board Type (B)	33813.20	2	16906.60	10.76**
Fidelity (F)	3949.96	2	1974.98	1.26
B x F	515.76	4	128.94	.08
Within	282816.00	180	1571.20	
Total	321094.92	188		

NOTE: ** $p<.01$

TABLE 26. BETWEEN BOARDS - POINTS PROBED (INCLUDES CONTROL GROUP)

ANOVA DATA TOTALS

	ACCESSIBILITY		
BOARD TYPE	100%	67%	33%
Power Supply	1289	1592	1284
First IF	878	812	852
Second IF	1077	691	825

TABLE 27. BETWEEN BOARDS ANOVA - POINTS PROBED (INCLUDES CONTROL GROUP)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Board Type (B)	33813.20	2	16906.60	10.81**
Accessibility (A)	2996.52	3	998.84	.64
B x A	7476.72	6	1246.12	.80
Within	276808.53	177	1563.89	
Total	321094.97	188		

NOTE: ** $p<.01$

TABLE 28. BETWEEN BOARDS - POINTS PROBED (INCLUDES CONTROL GROUP)

ANOVA DATA TOTALS

BOARD TYPE	PROFICIENCY HIGH	MEDIUM	LOW
Power Supply	1547	1264	1354
First IF	616	1132	794
Second IF	891	730	972

TABLE 29. BETWEEN BOARDS ANOVA - POINTS PROBED (INCLUDES CONTROL GROUP)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Board Type (B)	33813.20	2	16906.60	11.07**
Proficiency (P)	412.39	2	206.195	.14
B x P	12060.16	4	3015.04	1.97*
Within	274809.60	180		
Total	321095.35	188		

NOTE: ** $p<.01$
* $p<.05$

TABLE 30. BETWEEN BOARD/PROFICIENCY INTERACTION - MEAN POINTS PROBED

	PROFICIENCY		
PC BOARD	HIGH	MEDIUM	LOW
Power Supply	85.94	70.22	75.21
First IF	34.22	62.89	44.09
Second IF	49.50	40.56	54.00

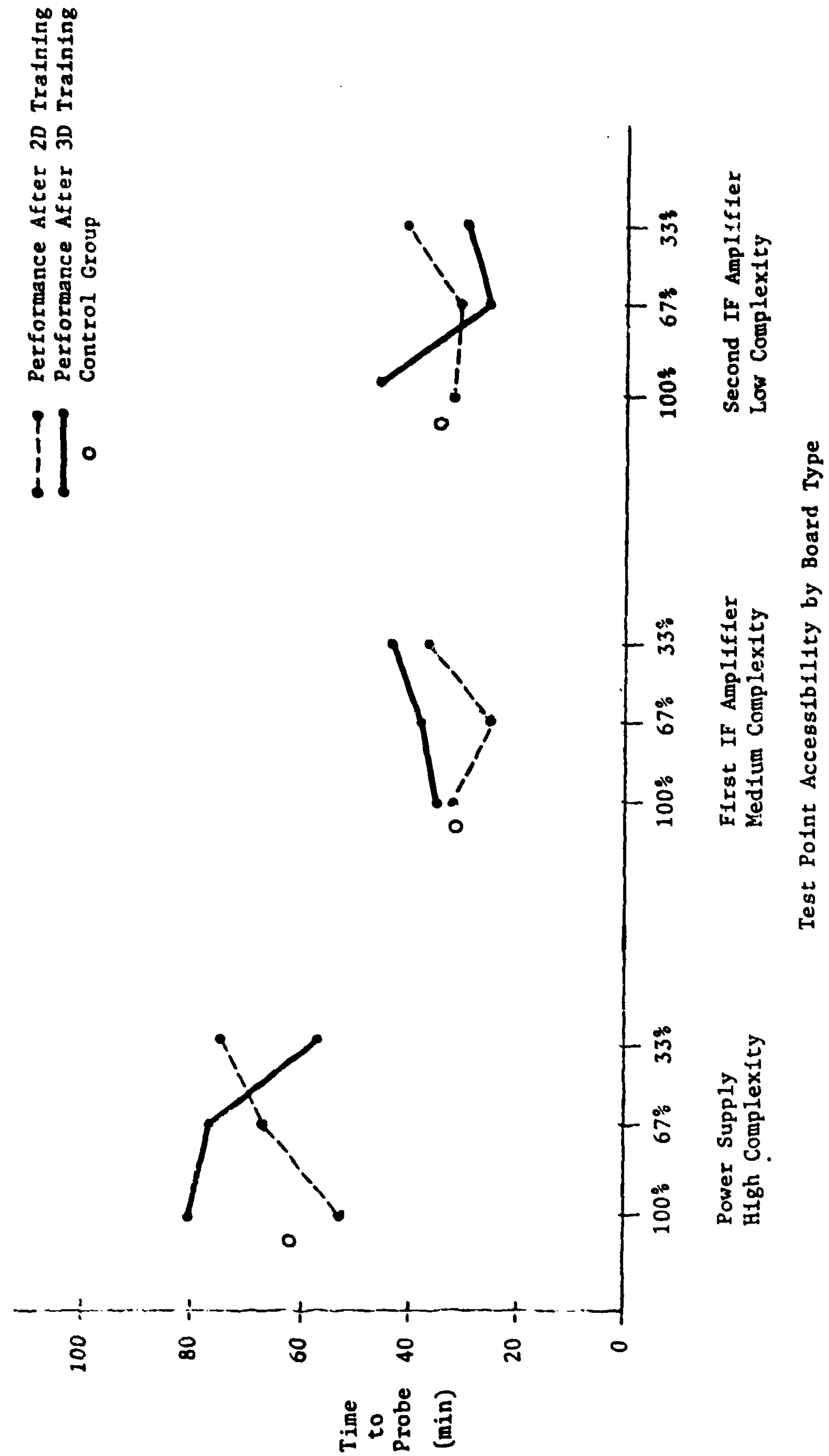

Figure 6. Probe time versus training test point accessibility criterion performance.

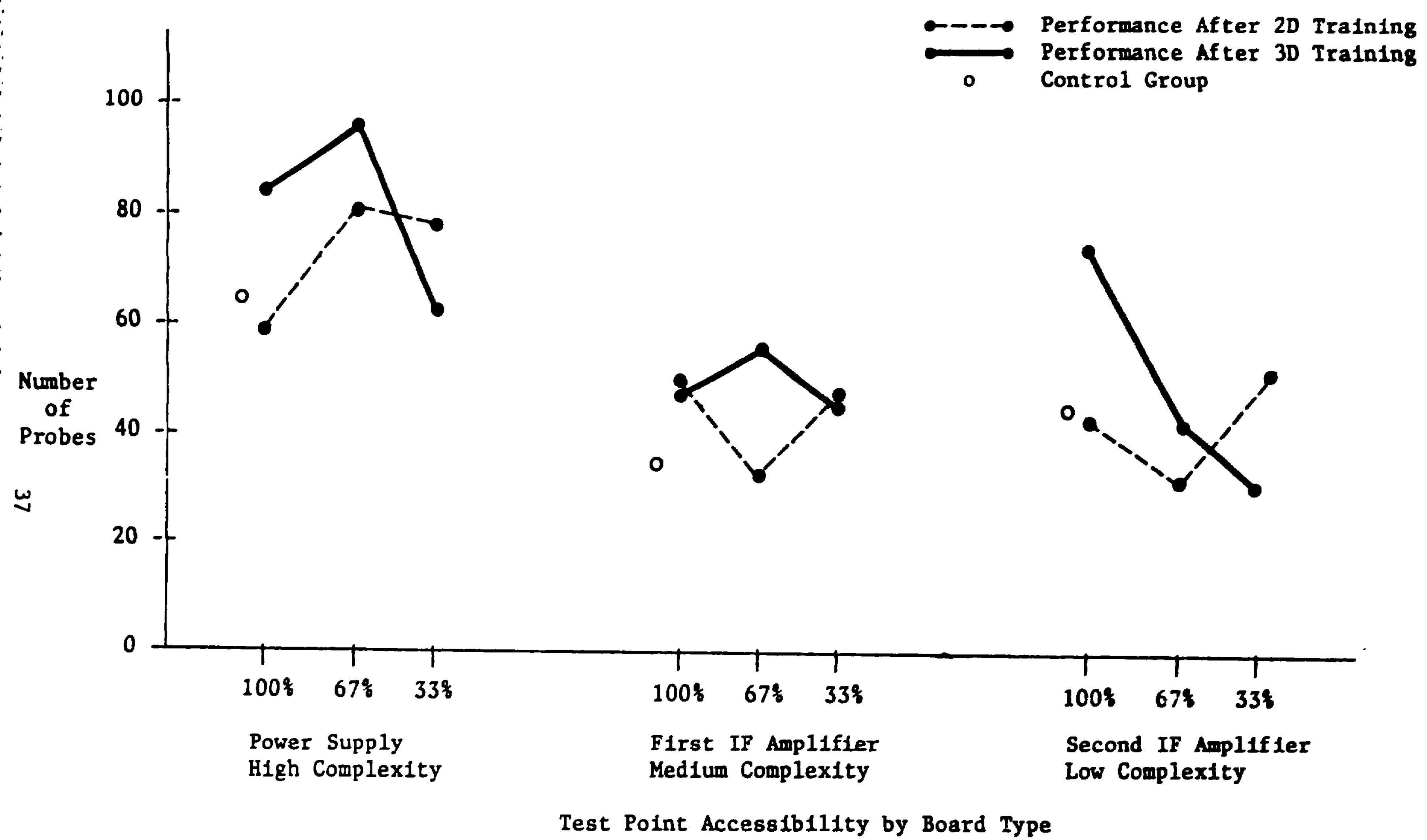

Figure 7. Number of probes versus training test point accessibility criterion performance.

CHI-SQUARE ANALYSIS - CRITERION TROUBLESHOOTING SUCCESS

If training effects of the modified and unmodified board treatment conditions were equal, then we would expect the number of students who had correctly diagnosed the fault before the first trip to the LS to be equal across conditions. Whether or not a student was correct on the first trip is a dichotomous variable which can be analyzed by using a Chi-Square test. This is a comparison of a set of observed frequencies (number correct on first trip) with a set of expected frequencies (expected equality of number correct).

Tables 31 through 33 contain the Chi Square frequencies for the 3 boards. As the probabilities indicate, there were no significant ($p<.05$) frequency differences between training conditions. The analysis indicates that test point accessibility had little effect on troubleshooting success. The success rate of the control group was not different from the success rate of the group trained on modified boards.

The troubleshooting success rate (Table 34) between the 3 boards was significantly different ($p=.025$). Further Chi Square analysis indicated that the Power Supply board had fewer students correct the first time ($p=.04$) than the First IF. There were no significant ($p<.05$) frequency differences between boards for the control group.

These data indicate that the type of board used had more of an impact on troubleshooting success than board fidelity. The students in the analysis were correct less often while troubleshooting the Power Supply board than during First or Second IF board troubleshooting.

ANALYSIS OF VARIANCE - MAIN EFFECTS - TRAINING PERFORMANCE

In addition to analysis on the criterion performance tests, student performance during training on the modified boards was examined. The dependent variables examined were number of probes during training and time to probe. Analysis of variance was used to determine treatment effects during training.

POWER SUPPLY BOARD - TREATMENT TRAINING EFFECTS. A three-way ANOVA on probe time during training on modified boards indicated a significant interaction ($p<.05$) between test point accessibility and proficiency (Tables 35 and 36). Table 37 contains the mean data for the accessibility/proficiency interaction. Medium proficiency students with 67% accessibility took more time to probe than medium/100% ($p<.05$) and medium/33% ($p<.01$). Additionally, with 67% test point accessibility, medium proficiency students had more probe time than high ($p<.01$) and low ($p<.05$) students. Analysis of the number of points probed during training resulted in no significant differences between treatment conditions (Tables 38 and 39).

POWER SUPPLY BOARD - TREATMENT VERSUS CONTROL TRAINING. The ANOVA data totals and summary tables (Tables 40-47) for training performance show no significant ($p<.05$) differences between treatments and control. These ANOVAs compared the main treatment effects to the control group in one-way ANOVA tests. These tests indicate no

TABLE 31. FAULT LOCATION SUCCESS RATE - CRITERION PERFORMANCE SECOND IF BOARD

	CORRECT FIRST TIME YES	CORRECT FIRST TIME NO
2D	16	11
3D	10	16
Control	4	5

$\chi^2 = 2.35$
$p = .31$

	CORRECT FIRST TIME YES	CORRECT FIRST TIME NO
100%	7	11
67%	10	8
33%	9	8
Control	4	5

$\chi^2 = 1.21$
$p = .75$

TABLE 32. FAULT LOCATION SUCCESS RATE - CRITERION PERFORMANCE - FIRST IF BOARD

	CORRECT FIRST TIME YES	CORRECT FIRST TIME NO
2D	19	8
3D	12	14
Control	5	4

$\chi^2 = 3.21$
$p = .19$

	CORRECT FIRST TIME YES	CORRECT FIRST TIME NO
100%	11	7
67%	10	8
33%	10	8
Control	5	4

$\chi^2 = .16$
$p = .98$

TABLE 33. FAULT LOCATION SUCCESS RATE - CRITERION PERFORMANCE POWER SUPPLY BOARD

	CORRECT FIRST TIME YES	CORRECT FIRST TIME NO
2D	8	19
3D	9	17
Control	3	6

$\chi^2 = .16$
$p = .92$

	CORRECT FIRST TIME YES	CORRECT FIRST TIME NO
100%	7	11
67%	3	15
33%	7	10
Control	3	6

$\chi^2 = 2.99$
$p = .22$

TABLE 34. FAULT LOCATION SUCCESS RATE - CRITERION PERFORMANCE - ALL BOARDS

	CORRECT FIRST TIME YES	CORRECT FIRST TIME NO
First IF Board	31	23
Second IF Board	26	26
Power Supply Board	17	36

$\chi^2 = 7.27$
$p = .03$

TABLE 35. POWER SUPPLY - TRAINING PERFORMANCE - PROBE TIME (MINUTES)

ANOVA DATA TOTALS

	THREE-DIMENSIONAL			TWO-DIMENSIONAL		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
100%	212	284	345	256	297	185
67%	165	554	310	228	518	226
33%	248	225	553	344	289	241

TABLE 36. POWER SUPPLY ANOVA - TRAINING PERFORMANCE - PROBE TIME (MINUTES)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility (A)	5394.92	2	2697.46	.80
Fidelity (F)	1802.67	1	1802.67	.53
Proficiency (P)	14253.59	2	7126.79	2.11
A x F Interaction	250.78	2	125.39	.04
A x P Interaction	36484.64	4	9121.16	2.70*
F x P Interaction	17754.33	2	8877.16	2.63
A x F x P	5305.88	4	1326.47	.39
Within Cells	121516.67	36	3375.46	
Total	202763.48	53		

Note: * $p<.05$

TABLE 37. POWER SUPPLY BOARD - TRAINING PERFORMANCE - ACCESSIBILITY/ PROFICIENCY INTERACTION - MEAN PROBE TIME (MINUTES)

	PROFICIENCY		
ACCESSIBILITY	HIGH	MEDIUM	LOW
100%	78.00	96.83	88.33
67%	65.50	178.67	89.33
33%	98.67	85.67	132.33

TABLE 38. POWER SUPPLY - TRAINING PERFORMANCE - POINTS PROBED

ANOVA DATA TOTALS

	THREE-DIMENSIONAL			TWO-DIMENSIONAL		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
100%	135	413	271	248	239	96
67%	206	264	353	163	324	107
33%	115	123	273	169	132	113

TABLE 39. POWER SUPPLY ANOVA - TRAINING PERFORMANCE - POINTS PROBED

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility (A)	8700.33	2	4350.17	1.24
Fidelity (F)	5848.96	1	5848.96	1.66
Proficiency (P)	5954.33	2	2977.17	.85
A x F Interaction	681.38	2	340.69	.09
A x P Interaction	8205.34	4	2051.34	.58
F x P Interaction	14371.15	2	7185.58	2.04
A x F x P	7137.18	4	1784.30	.51
Within Cells	126721.33	36	3520.03	
Total	177620.00	53		

Note: No Significant Effects

TABLE 40. POWER SUPPLY - TRAINING PERFORMANCE - PROBE TIME (MINUTES) (FIDELITY AND CONTROL)

FIDELITY	ANOVA DATA TOTALS
Two-Dimensional	2584 (N=27)
Three-Dimensional	2896 (N=27)
Control	722 (N=9)

TABLE 41. POWER SUPPLY ANOVA - TRAINING PERFORMANCE - PROBE TIME (MINUTES) FIDELITY (INCLUDES CONTROL GROUP)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Fidelity	6016.06	2	3008.03	.00
Within	204253.20	60	3404.22	.00
Total	210269.26	62		

Note: No Significant Effects

TABLE 42. POWER SUPPLY - TRAINING PERFORMANCE - POINTS PROBED (FIDELITY AND CONTROL)

FIDELITY	ANOVA DATA TOTALS
Two-Dimensional	1591 (N=27)
Three-Dimensional	2153 (N=27)
Control	684 (N=9)

TABLE 43. POWER SUPPLY ANOVA - TRAINING PERFORMANCE - POINTS PROBED FIDELITY (INCLUDES CONTROL GROUP)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Fidelity	8675.26	2	4337.63	1.44
Within	179892.00	60	2998.20	
Total	188567.26	62		

Note: No Significant Effects

TABLE 44. POWER SUPPLY - TRAINING PERFORMANCE - PROBE TIME (MINUTES) (ACCESSIBILITY AND CONTROL)

ACCESSIBILITY	ANOVA DATA TOTALS
100%	1579 (N=18)
67%	2001 (N=18)
33%	1900 (N=18)
Control	723 (N=9)

TABLE 45. POWER SUPPLY ANOVA - TRAINING PERFORMANCE - PROBE TIME (MINUTES) ACCESSIBILITY (INCLUDES CONTROL GROUP)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility	11559.60	3	3853.20	1.14
Within	198684.86	59	3367.54	
Total	210244.46	62		

Note: No Significant Effects

TABLE 46. POWER SUPPLY - TRAINING PERFORMANCE - POINTS PROBED (ACCESSIBILITY AND CONTROL)

ACCESSIBILITY	ANOVA DATA TOTALS
100%	1402 (N=18)
67%	1417 (N=18)
33%	925 (N=18)
Control	684 (N=9)

TABLE 47. POWER SUPPLY ANOVA - TRAINING PERFORMANCE - POINTS PROBED ACCESSIBILITY (INCLUDES CONTROL GROUP)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility	7919.37	3	2639.79	.86
Within	180647.97	59	3061.83	
Total	188567.42	62		

Note: No Significant Effects

significant ($p<.05$) differences during training between modified and unmodified boards.

SECOND IF BOARD - TREATMENT TRAINING EFFECTS. A three-way ANOVA on probe time during training resulted in a significant ($p<.05$) two-way interaction between fidelity and proficiency and a three-way interaction between test point accessibility, fidelity, and proficiency (Tables 48 and 49). An LSD post hoc analysis on the fidelity/proficiency interaction (Table 50) determined the low proficiency group had less probe time ($p<.05$) with 2D fidelity than 3D. Additional significance was found between high and low proficiency during 3D training.

The mean data for the accessibility/fidelity/proficiency interaction is contained in Table 51. Post hoc analysis compared the differences of mean probe time within and between factors. All significant interaction differences were found in the 33% level of test point accessibility and the following is limited to that level. The difference between 2D high proficiency and 2D medium proficiency was significantly ($p<.01$) more than the difference between 3D high proficiency and 3D medium proficiency. The difference between 2D high proficiency and 2D low proficiency is significantly ($p<.01$) less than the difference between the same 3D factors. The difference between 2D medium proficiency and low proficiency is significantly ($p<.05$) less than the difference between the same 3D factors. Overall, this interaction is indicating that, within the 33% accessibility category, the mean probe time differences among the proficiency levels are not consistent across fidelity. From the patterns in Figure 8, it can be seen that medium proficiency dramatically breaks its pattern in the 33% level and the other proficiencies do not.

A three-way ANOVA on points probed during training failed to indicate any significant ($p<.05$) treatment effects. Table 52 contains the ANOVA totals and Table 53 the summary data.

SECOND IF BOARD - TREATMENT VERSUS CONTROL TRAINING. The ANOVA data totals and summary tables (Tables 54 - 61) for training performance indicate no significant differences between treatments and control during training.

FIRST IF BOARD - TREATMENT TRAINING EFFECTS. A three-way ANOVA on probe time during training on the modified First IF boards indicated a significant ($p<.01$) proficiency effect (Tables 62 and 63). A post hoc LSD indicates the high proficiency group had less probe time than the medium ($p<.05$) and low ($p<.01$) groups.

There were no significant ($p<.05$) treatment effects during training on the number of points probed (Tables 64 and 65).

FIRST IF BOARD - TREATMENT VERSUS CONTROL TRAINING. The ANOVA data totals and summaries are shown in Tables 66 - 73. The main effects of fidelity and accessibility were not significantly ($p<.05$) different from the control group on number of points probed. The additional

TABLE 48. SECOND IF - TRAINING PERFORMANCE - PROBE TIME (MINUTES)

ANOVA DATA TOTALS

	THREE-DIMENSIONAL			TWO-DIMENSIONAL		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
100%	105	145	148	115	85	94
67%	105	162	134	165	75	80
33%	74	75	195	108	194	137

TABLE 49. SECOND IF ANOVA- TRAINING PERFORMANCE - PROBE TIME (MINUTES)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility (A)	240.11	2	120.05	.42
Fidelity (F)	150.00	1	150.00	.53
Proficiency (P)	375.11	2	187.56	.66
A x F Interaction	1186.56	2	593.27	2.08
A x P Interaction	1820.45	4	455.11	1.60
F x P Interaction	2025.33	2	1012.66	3.55*
A x F x P	3201.76	4	800.44	2.81*
Within Cells	10266.67	36	285.18	
Total	19265.99	53		

Note: * $p<.05$

TABLE 50. SECOND IF - TRAINING PERFORMANCE - FIDELITY/PROFICIENCY INTERACTION - MEAN PROBE TIME (MINUTES)

	FIDELITY	
PROFICIENCY	TWO-DIMENSIONAL	THREE-DIMENSIONAL
High	43.11	31.55
Medium	39.33	42.44
Low	34.57	53.00

TABLE 51. SECOND IF - TRAINING PERFORMANCE - THREE-WAY INTERACTION MEAN PROBE TIME (MINUTES)

	THREE-DIMENSIONAL			TWO-DIMENSIONAL		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
100%	35.00	46.33	49.33	38.33	28.33	31.33
67%	35.00	54.00	44.67	55.00	25.00	26.67
33%	24.67	25.00	65.00	36.00	64.67	45.67

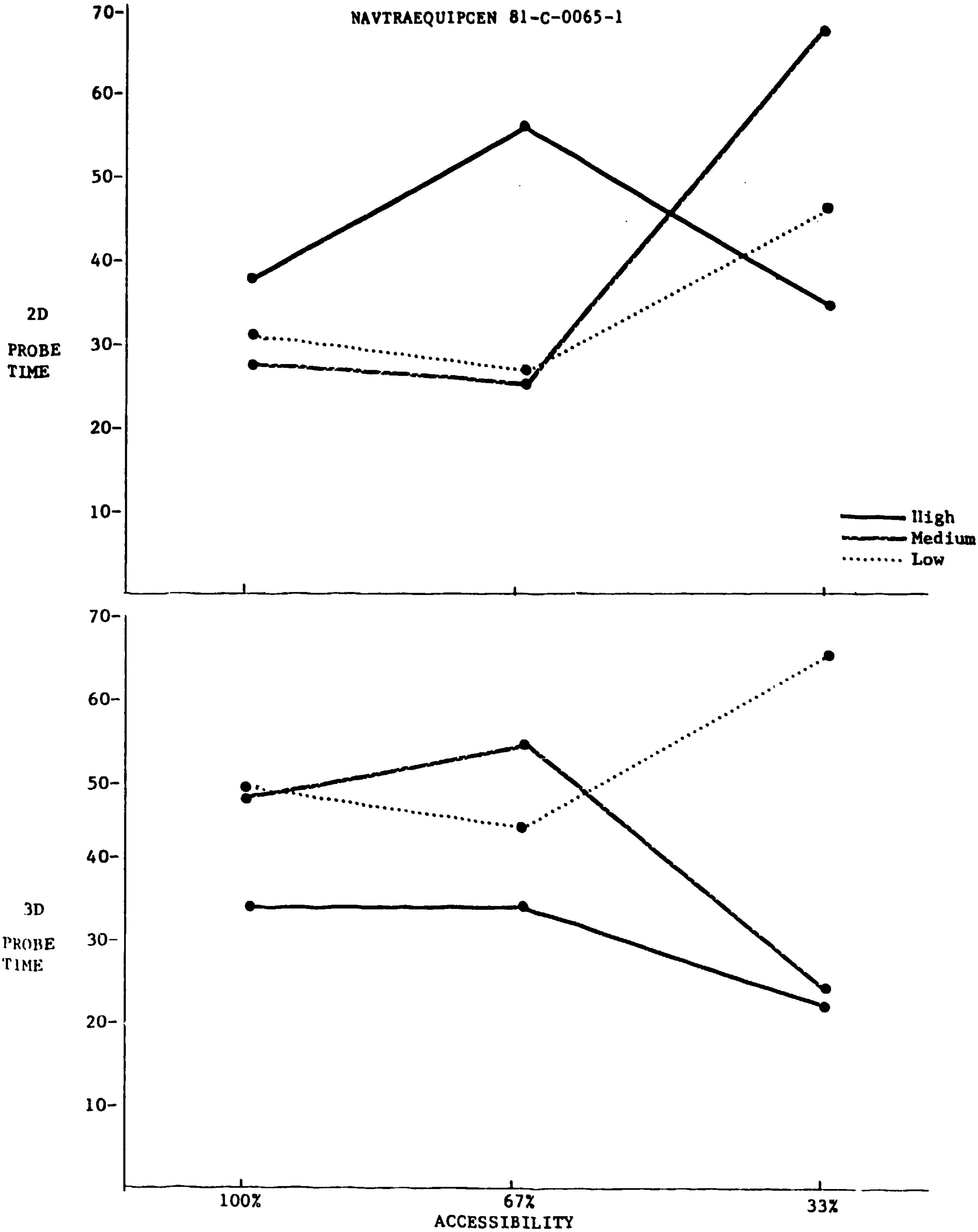

Figure 8. Second IF training performance - probe time (minutes).

TABLE 52. SECOND IF - TRAINING PERFORMANCE - POINTS PROBED

ANOVA DATA TOTALS

	THREE-DIMENSIONAL			TWO-DIMENSIONAL		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
100%	194	249	126	150	102	144
67%	114	185	108	162	109	62
33%	52	109	139	104	206	116

TABLE 53. SECOND IF ANOVA - TRAINING PERFORMANCE - POINTS PROBED

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility (A)	1998.92	2	999.46	1.13
Fidelity (F)	271.13	1	271.13	.31
Proficiency (P)	2048.92	2	1024.46	1.16
A x F Interaction	2577.82	2	1288.91	1.46
A x P Interaction	2267.97	4	566.99	.64
F x P Interaction	929.60	2	464.80	.53
A x F x P	4005.95	4	1001.48	1.13
Within Cells	31816.67	36	883.79	
Total	45916.98	53		

Note: No Significant Effects

TABLE 54. SECOND IF - TRAINING PERFORMANCE - PROBE TIME (MINUTES) (FIDELITY AND CONTROL)

FIDELITY	ANOVA DATA TOTALS
Two-Dimensional	1053 (N-27)
Three-Dimensional	1142 (N=27)
Control	302 (N=9)

TABLE 55. SECOND IF ANOVA - TRAINING PERFORMANCE - PROBE TIME (MINUTES) FIDELITY (INCLUDES CONTROL GROUP)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Fidelity	358.38	2	179.19	.42
Within	25271.40	60	421.19	
Total	25629.78	62		

Note: No Significant Effects

TABLE 56. SECOND IF - TRAINING PERFORMANCE -- POINTS PROBED (FIDELITY AND CONTROL)

FIDELITY	ANOVA DATA TOTALS
Two-Dimensional	1155 (N=27)
Three-Dimensional	1276 (N=27)
Control	491 (N=9)

TABLE 57. SECOND IF ANOVA - TRAINING PERFORMANCE - POINTS PROBED FIDELITY (INCLUDES CONTROL GROUP)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Fidelity	1046.98	2	523.49	.43
Within	73767.60	60	1229.46	
Total	74814.58	62		

Note: No Significant Effects

TABLE 58. SECOND IF - TRAINING PERFORMANCE - PROBE TIME (MINUTES)
(ACCESSIBILITY AND CONTROL)

ACCESSIBILITY	ANOVA DATA TOTALS
100%	692 (N=18)
67%	721 (N=18)
33%	783 (N=18)
Control	302 (N=9)

TABLE 59. SECOND IF ANOVA - TRAINING PERFORMANCE - PROBE TIME (MINUTES)
ACCESSIBILITY (INCLUDES CONTROL GROUP)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility	658.20	3	219.40	.52
Within	24777.46	59	419.96	
Total	25435.66	62		

Note: No Significant Difference

TABLE 60. SECOND IF - TRAINING PERFORMANCE - POINTS PROBED (ACCESSIBILITY AND CONTROL)

ACCESSIBILITY	ANOVA DATA TOTALS
100%	965 (N=18)
67%	740 (N=18)
33%	726 (N=18)
Control	491 (N=9)

TABLE 61. SECOND IF ANOVA - TRAINING PERFORMANCE - POINTS PROBED ACCESSIBILITY (INCLUDES CONTROL GROUP)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility	2700.63	3	900.21	.74
Within	71444.28	59	1210.92	
Total	74144.91	62		

Note: No Significant Difference

TABLE 62. FIRST IF - TRAINING PERFORMANCE - PROBE TIME (MINUTES)

ANOVA DATA TOTALS

	THREE-DIMENSIONAL			TWO-DIMENSIONAL		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
100%	80	153	236	93	191	151
67%	124	146	172	114	128	128
33%	73	99	233	124	183	148

TABLE 63. FIRST IF ANOVA - TRAINING PERFORMANCE - PROBE TIME (MINUTES)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility (A)	235.26	2	117.63	.23
Fidelity (F)	58.07	1	58.07	.11
Proficiency (P)	6020.15	2	3010.07	5.95**
A x F Interaction	433.04	2	216.52	.43
A x P Interaction	1401.18	4	350.29	.69
F x P Interaction	449.04	2	224.52	.44
A x F x P	2929.85	4	732.46	1.44
Within Cells	18200.67	36	505.57	
Total	29727.26	53		

Note: ** p<.01

TABLE 64. FIRST IF - TRAINING PERFORMANCE - POINTS PROBED

ANOVA DATA TOTALS

	THREE-DIMENSIONAL			TWO-DIMENSIONAL		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
100%	81	109	163	111	309	125
67%	135	226	127	112	99	153
33%	91	88	170	120	189	117

TABLE 65. FIRST IF ANOVA - TRAINING PERFORMANCE - POINTS PROBED

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility (A)	429.15	2	214.58	.18
Fidelity (F)	389.35	1	389.35	.34
Proficiency (P)	3817.59	2	1908.79	1.67
A x F Interaction	2842.26	2	1421.13	1.24
A x P Interaction	1550.30	4	387.57	.33
F x P Interaction	1599.36	2	799.68	.70
A x F x P	7423.86	4	1855.96	1.62
Within Cells	41134.00	36	1142.61	
Total	59185.87	53		

Note: No Significant Effects

TABLE 66. FIRST IF - TRAINING PERFORMANCE - PROBE TIME (MINUTES) (FIDELITY, PROFICIENCY, AND CONTROL)

ANOVA DATA TOTALS

FIDELITY	PROFICIENCY HIGH	MEDIUM	LOW
Two-Dimensional	331	502	427
Three-Dimensional	277	398	641
Control	85	116	73

TABLE 67. FIRST IF ANOVA - TRAINING PERFORMANCE - PROBE TIME (MINUTES) FIDELITY BY PROFICIENCY (INCLUDES CONTROL GROUP)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Fidelity (F)	2355.96	2	1177.98	2.85
Proficiency (P)	5089.74	2	2544.87	6.16**
F x P	4507.68	4	1126.92	2.73**
Within	22284.01	54	412.67	
Total	34237.39	62		

Note: ** p<.01

TABLE 68. FIRST IF - TRAINING PERFORMANCE - POINTS PROBED

FIDELITY	ANOVA DATA TOTALS
Two-Dimensional	1335 (N=27)
Three-Dimensional	1190 (N=27)
Control	419 (N=9)

TABLE 69. FIRST IF ANOVA - TRAINING PERFORMANCE - POINTS PROBED FIDELITY (INCLUDES CONTROL GROUP)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Fidelity	389.72	2	194.86	.15
Within	76284.60	60	1271.41	
Total	76674.32	62		

Note: No Significant Effects

TABLE 70. FIRST IF - TRAINING PERFORMANCE - PROBE TIME (MINUTES) (ACCESSIBILITY, PROFICIENCY, AND CONTROL)

ANOVA DATA TOTALS

	PROFICIENCY		
ACCESSIBILITY	HIGH	MEDIUM	LOW
100%	173	344	387
67%	238	274	300
33%	197	282	381
Control	85	116	73

TABLE 71. FIRST IF ANOVA - TRAINING PERFORMANCE - PROBE TIME (MINUTES) ACCESSIBILITY BY PROFICIENCY (INCLUDES CONTROL GROUP)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility (A)	2533.11	3	844.37	1.79
Proficiency (P)	5089.74	2	2544.87	5.41**
A x P	2659.86	6	443.31	.94
Within	23954.70	51	469.70	
Total	34237.41	62		

Note: ** p<.01

TABLE 72. FIRST IF - TRAINING PERFORMANCE - POINTS PROBED (ACCESSIBILITY AND CONTROL)

ACCESSIBILITY	ANOVA DATA TOTALS
100%	868 (N=18)
67%	852 (N=18)
33%	775 (N=18)
Control	419 (N=9)

TABLE 73. FIRST IF ANOVA - TRAINING PERFORMANCE - POINTS PROBED ACCESSIBILITY (INCLUDES CONTROL GROUP)

ANOVA SUMMARY

VARIATION SOURCE	SUM OF SQUARES	DEGREES FREEDOM	VARIANCE ESTIMATE	F
Accessibility	275.64	3	91.88	.069
Within	77928.38	59	1320.82	
Total	78204.02	62		

Note: No Significant Difference

factor of proficiency was included in the time probed ANOVAs due to a significant effect found in Table 63. Table 67 indicates a significant ($p<.01$) proficiency effect and a significant ($p<.01$) fidelity/proficiency interaction. Post hoc analysis (LSD) indicated that the high proficiency students had less probe time than medium ($p<.05$) or low ($p<.01$) proficiencies. A Scheffé post hoc (Winer, 1962) was used on the fidelity/proficiency interaction, due to unequal cell sizes. However, the pair-wise analysis failed to find significance, indicating a higher order complex interaction. The impact of analysis on combined pairs is negligible in this research.

TRAINING PERFORMANCE SUMMARY

There were no significant performance differences during training between unmodified and modified boards. The low fidelity modified boards resulted in training performance (in terms of probes) equal to, or in some cases better than, the higher fidelity modified and unmodified boards. Figures 9 and 10 illustrate the performance patterns. The modified boards tended to have more significant complex differences and interactions. These data were not as predictable as the criterion performance, but still indicate that high fidelity is not necessarily the best. Reducing fidelity and accessibility tends to lower troubleshooting probes on the Power Supply board. The apparent lower probe time for unmodified control boards in Figure 10 was not found to be statistically significant.

Student proficiency level affected training performance. High proficiency students tended to probe fewer points than the medium and low groups. Within the low proficiency group, students used more time to probe on the lower fidelity boards. On 2D boards probe time increased with increasing proficiency, and on 3D boards probe time decreased with increasing proficiency.

TEST POINT ACCESSIBILITY RATIO

Data reported in previous sections indicated an equal training effectiveness between actual equipment, high fidelity, and low fidelity. In some cases, the lower fidelity simulation proved to be more effective than higher fidelity. Given these results, the training equipment designer still asks the question, "What is the minimum number of accessible test points required for effective training?" This is a critical question because increasing the number of active test points on a maintenance trainer has substantial cost implications.

Naturally a trainer for a board with more test points is likely to require more active points than is a trainer for a board with fewer points. In addition, 2 different faults on the same board may require a different number of probes to troubleshoot due to the differences in symptoms.

The half-split technique is commonly accepted as the most efficient troubleshooting procedure because a fault can be located with a minimum number of probes in minimum time. In the half-split

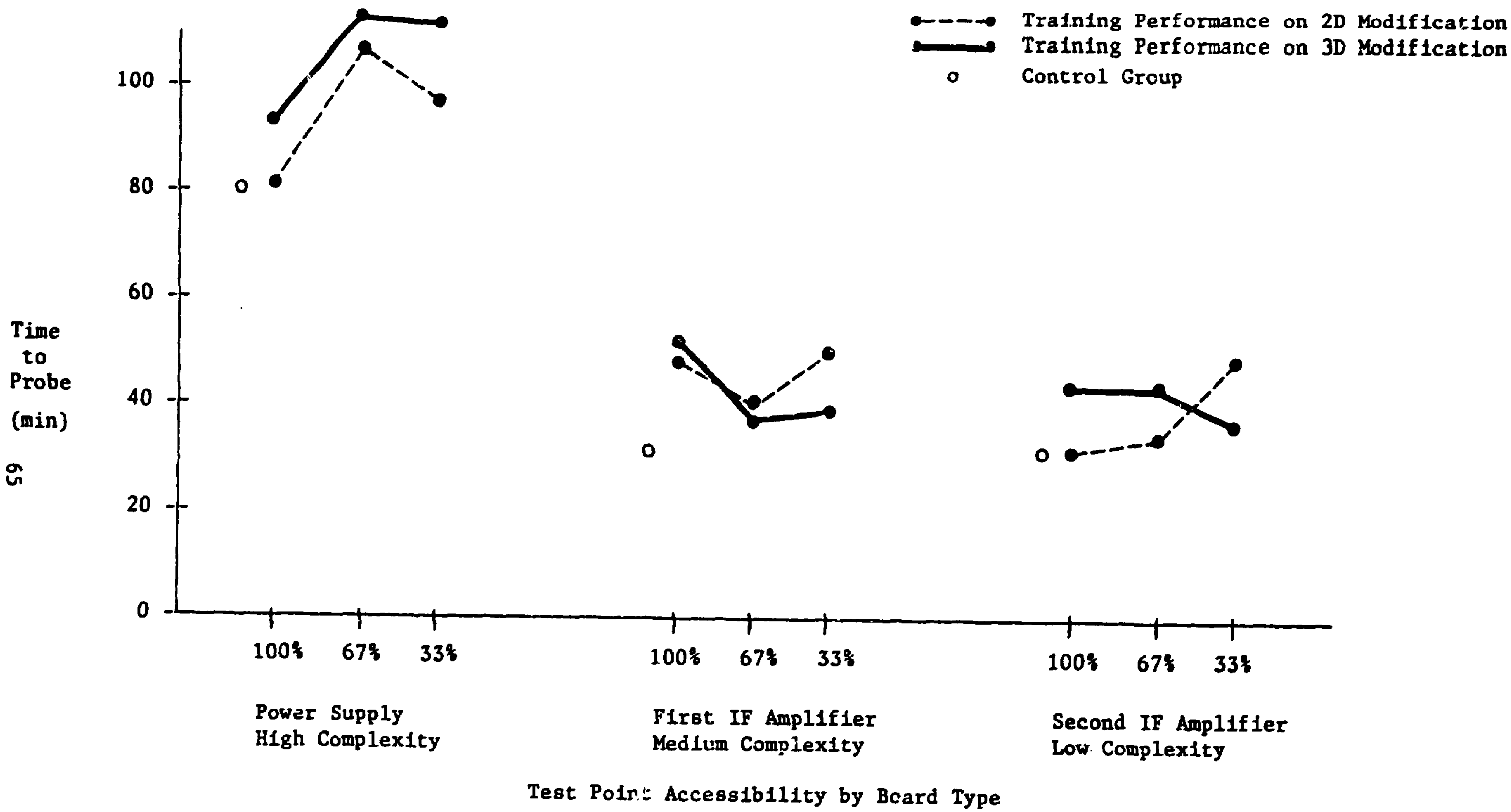

Figure 9. Probe time versus training test point accessibility training performance.

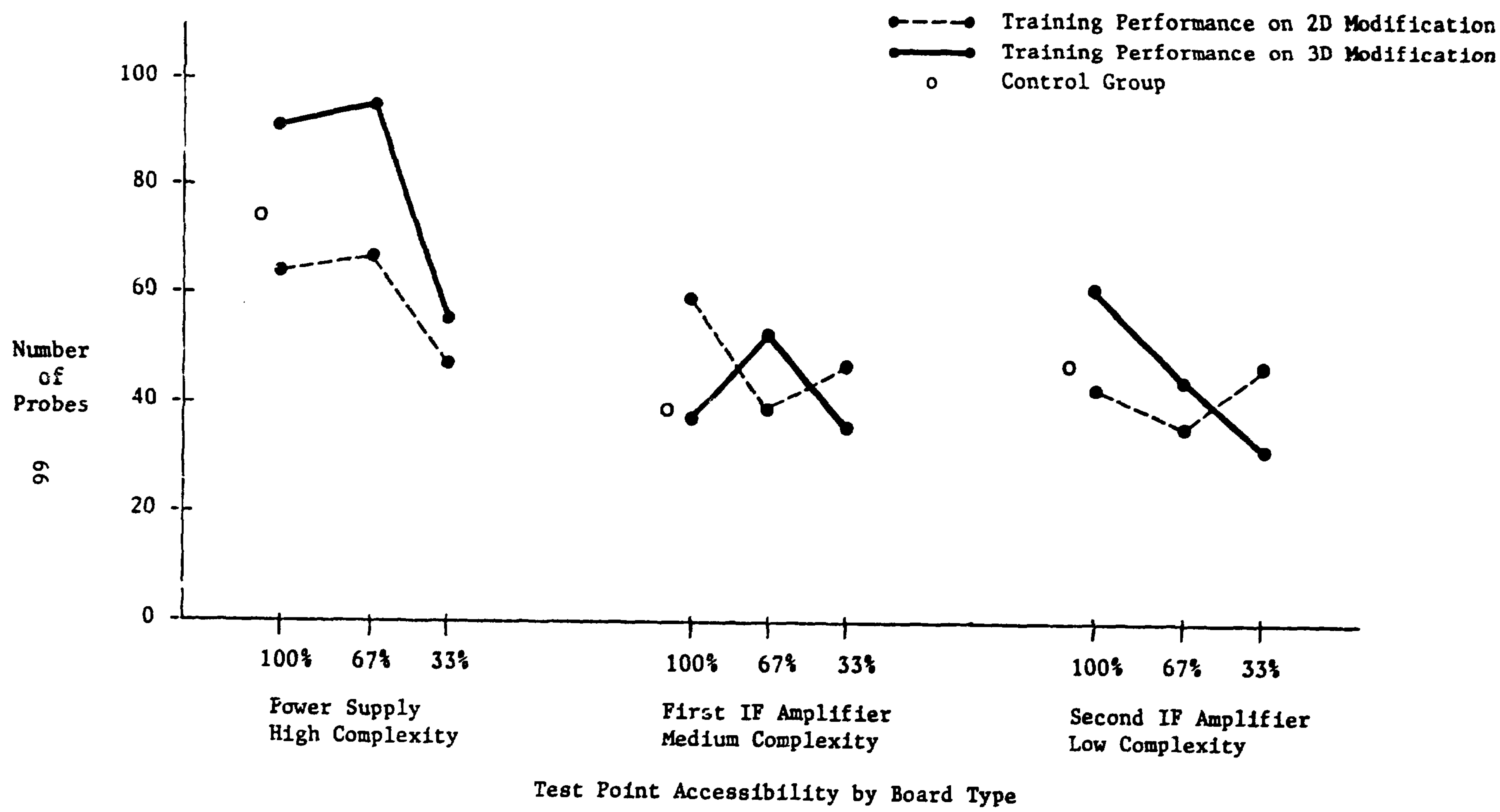

Figure 10. Number of probes versus training test point accessibility training performance.

technique, the troubleshooter successively probes the midpoint between known good and bad signal until the faulty component is located. Since the half-split technique represents optimum troubleshooting behavior, it is a logical tool for determining the number of active points required to teach efficient troubleshooting. A maintenance trainer should have active those points required to locate the fault using the half-split technique plus enough distractor points to prevent unnecessarily channeling the student to the fault.

An analysis was performed to determine the minimum accessibility ratio required for effective training. The accessibility ratio is the number of points made accessible to the student divided by the minimum number of points that must be probed to locate the fault utilizing the half-split technique. Since the ultimate objective of troubleshooting is to locate the fault in the minimum time, probe time was chosen as the measure of effectiveness in this analysis.

Figure 11 contains the probe time during testing plotted by average accessibility ratio during training for each board. Note that the Power Supply board has approximately the same accessibility ratios as the First IF board but required nearly twice as long to troubleshoot. Since the Power Supply board had only a few more test points than the First IF board (see Table 1), this increased troubleshooting time was not due to increased complexity in terms of number of test points. The Power Supply board has extensive feedback loops which the students could not efficiently troubleshoot, thus leading to a large number of unproductive probes. Results across board types indicated a significant performance difference between the Power Supply board and the First and Second IF boards. Since student performance was apparently due more to logic misunderstanding than number of accessible test points, results on the Power Supply board are of limited value in determining the effects of test point accessibility on student performance and are not included in the following discussion.

Minimum probe time on the 3D boards ranged from an accessibility ratio of 1.5 on the Second IF board to 7.5 on the First IF board. For 2D boards, optimum performance ranged from an accessibility ratio of 2.75 to 5.5. These wide ranges were due to the intersubject variability between the various treatment effects. Results for the First IF and Second IF boards were combined in order to determine the overall trends in student performance. These results appear in Figure 12. Note that for both 2D and 3D boards optimum student performance in testing occurs after training with a 4 to 1 accessibility ratio. The minimum number of active points required for effective training is 4 times as many points as those required to locate the fault using the half-split technique.

STUDENT COMMENTS

Student comments at the researcher's station were recorded, and the predominant ones follow:

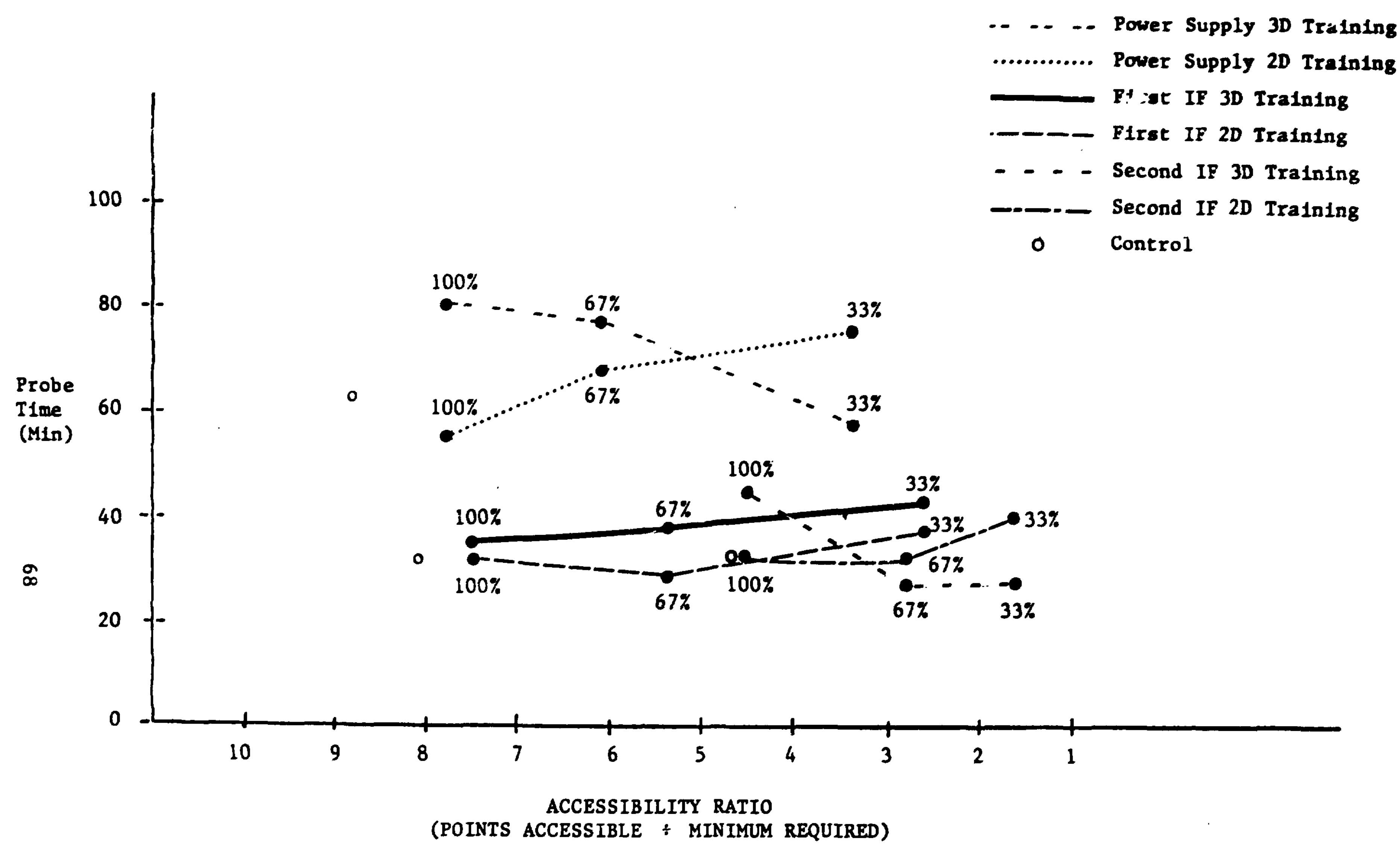

Figure 11. Student performance by accessibility ratio.

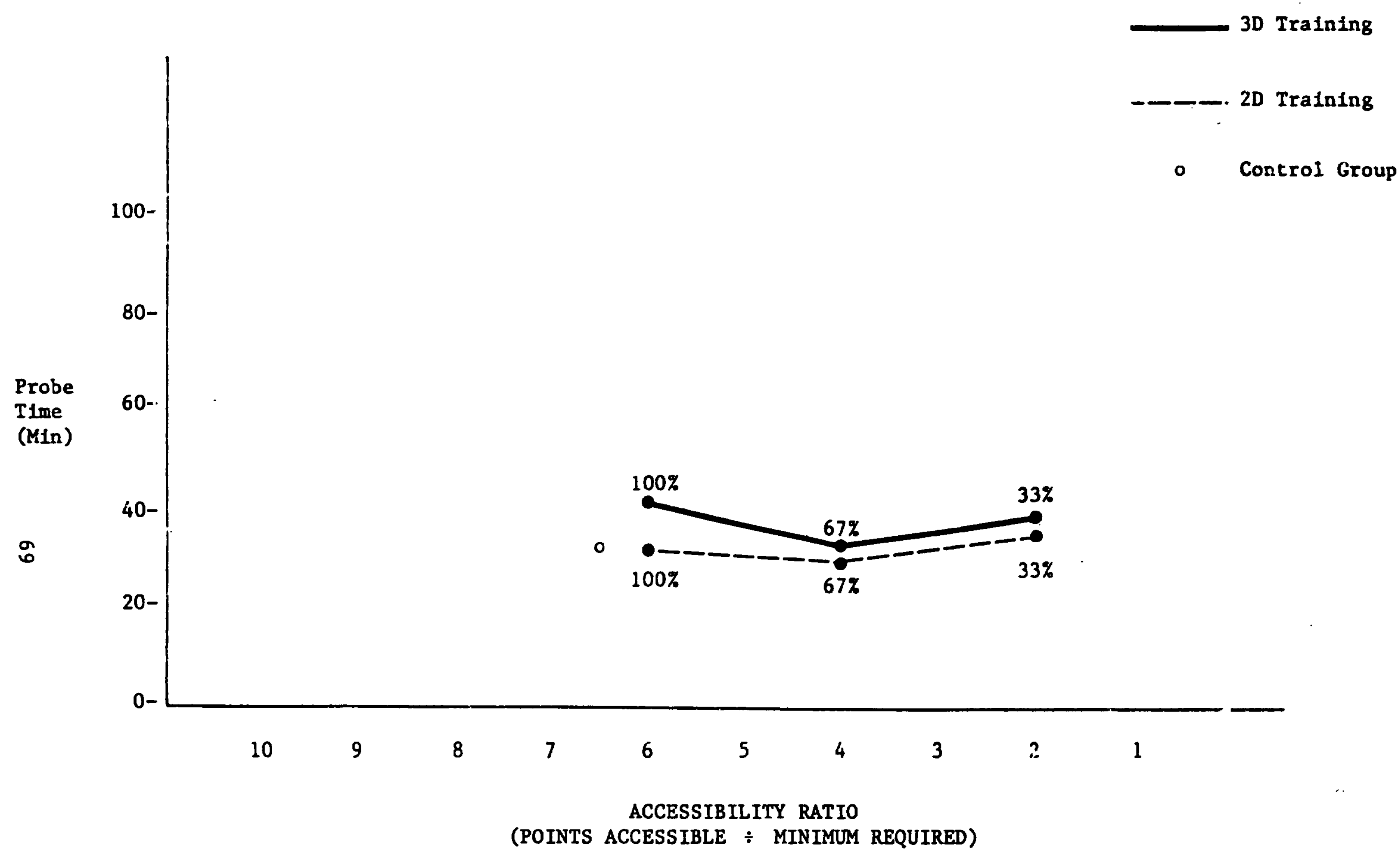

Figure 12. Overall student performance by accessibility ratio. First IF and Second IF boards combined.

RE: Research

a. Do not like being watched at researcher's station.

b. Enjoy researcher's Performance Tests and feel performance has thus improved on school's tests.

c. Three-dimensional boards appear cluttered.

d. Cannot see solder runs on the researcher's modified boards from the front.

e. Would prefer a mat finish photo on the 2D boards over the glossy.

Students were generally receptive to the on-site researcher and the testing environment. Student comments regarding curriculum indicate a weak understanding of some BE&E principles. After an initial familiarization, the modified PC boards were accepted. Most negative comments referred to the lack of extra troubleshooting cues as in actual equipment, e.g. the solder run visibility from the front.

SECTION IV

CONCLUSIONS & RECOMMENDATIONS

If actual equipment or AETs are required for training effectiveness, then the control group trained on unmodified boards should have performed significantly better than all other groups. The research compared treatment conditions and a control in a strict experimental environment. The results indicated no significant differences when comparing the experimental treatments to the control group. The control group trained on unmodified boards tended to have an equal or higher number of probes, and equal or more probe time during testing than the students trained on lower fidelity boards. The control group trained on unmodified boards did not have a significantly higher troubleshooting success rate than students trained on modified boards. On several boards, the proportion of success to failure tended to be better after training on modified 2D boards. Overall, the significant and non-significant data indicate that actual equipment is not superior to modified equipment for electronic training in this environment.

If high fidelity simulation was necessary for training effectiveness, then the 3D/100% training should have resulted in better performance than all other modifications. When compared with the control group, the lower fidelities tended to have shorter probe times with fewer probes. In the board modifications, the 3D/33% training had fewer probes than the other 3D treatments. Training on 2D/100% had fewer probes than 3D/100%, and the 2D group tended to have a higher troubleshooting success rate than the 3D group. These data indicate that high fidelity is not required for training effectiveness.

During training on the 3 modified boards, the 2D/33% training, 2D/67% training, and 3D/33% training had the fewest number of points probed. The unmodified and high fidelity boards did not result in the best training performance. The control group tended to have a shorter probing time during training than the experimental groups, but this difference was not statistically significant.

Student proficiency level within this school strongly affects the student's troubleshooting results. Low proficiency students, as expected, took a longer time to localize faults and probed more points than medium or high proficiency students. These expected results and their consistency supports proficiency level, as detailed for this analysis, as a valid performance predictor.

Student performance on the Power Supply board was significantly different from the First and Second IFs. It appears that the students do not understand the concepts required to efficiently troubleshoot this board.

For this type of hands-on electronics maintenance training, the research has shown that low fidelity simulation can be as effective as high fidelity trainers or actual equipment. Performance indicates that lower fidelity training with reduced test point accessibility can decrease fault localization time and number of probes during testing.

Transfer-of-training to actual equipment appears to be enhanced by selective test point reduction, not one-to-one fidelity with the actual equipment. Optimum student performance in testing appears to occur when the accessibility ratio in training is approximately four to one.

In general, the research has indicated:

a. Student proficiency level (based on BE&E completion times) can be used to predict performance in ET Splice School. Low proficiency students should be given tutorial help to improve their ET Splice School performance.

b. Actual equipment trainers are not superior to lower fidelity trainers for electronic training of this type.

c. Optimum troubleshooting performance (based on number of probes and probing time) occurs after training with a 4 to 1 ratio between active test points and those required to isolate the fault using optimum troubleshooting procedures.

d. Students in this research accepted the simulated low fidelity equipment.

e. The First and Second IF Boards lead to more efficient troubleshooting when compared to the Power Supply Board.

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GLOSSARY

AET	Actual Equipment Trainer
B	Transistor Base
BE&E	Basic Electricity and Electronics School
Ca	Capacitor
C	Transistor Collector
CMI	Computer Managed Instruction
CR	Diode
2D	Two-Dimensional
3D	Three-Dimensional
E	Transistor Emitter
ET	Electronic Technician
First IF	First Intermediate Frequency Board (Medium Complexity)
LS	Learning Supervisor
LSD	Least Significant Difference
Power Supply	Power Supply Board (High Complexity)
PC	Printed Circuit Board
Q	Transistor
R	Resistor
Run	Conductive Part of Printed Circuit Board
Second IF	Second Intermediate Frequency Board (Low Complexity)
T	Transformer
VCC	Static Operating Potential

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